DYNAMIC RESULTS FOR CLOSEDLOOP BSM1
(Results from Matlab/Simulink implementation by Dr Ulf Jeppsson, IEA, Lund University, Sweden, May 21 2009 – based on Matlab R2008b (ver 7.7.0))

SUMMARY OF PLANT PERFORMANCE
****
The plant was simulated in closed loop for 500 days to achieve quasi steady state using the CONSTANT INPUT file (ideal sensors and actuators used). Then the DRYWEATHER file was used to simulate the closed loop dynamics during 14 days and set up the plant for the dynamic benchmark simulations (using active noise and delay on sensors and actuators).
The results of this simulation was used as initial values for the actual plant performance calculations using the different dynamic input files.

Default controllers:
controller for DO in tank 5, DOsetpoint=2mg/l, Sensor model A, Actuator model used, Noise data from file column 1;
controller for NO3-N in tank 2, NO3setpoint=1mg/l, Sensor model B0, Noise data from file column 2.

Evaluation is based on data every 15 minutes and uses zero-order hold (forward Euler) for integration between measurements.

****
* DRYWEATHER FILE *
****

Overall plant performance during time 7 to 14 days
****

Effluent average concentrations based on load

Effluent average flow rate = 18057.8774 m3/d
Effluent average SI conc = 30 mg COD/l
Effluent average SS conc = 0.88177 mg COD/l
Effluent average XI conc = 4.5728 mg COD/l
Effluent average XS conc = 0.20084 mg COD/l
Effluent average XBH conc = 10.2314 mg COD/l
Effluent average XBA conc = 0.57803 mg COD/l
Effluent average XP conc = 1.7553 mg COD/l
Effluent average SO conc = 1.9881 mg (-COD)/l
Effluent average SNO conc = 12.4199 mg N/l
Effluent average SNH conc = 2.5392 mg N/l (limit = 4 mg N/l)
Effluent average SND conc = 0.70651 mg N/l
Effluent average XND conc = 0.01442 mg N/l
Effluent average SALK conc = 4.0409 mol HCO3/m3
Effluent average TSS conc = 13.0038 mg SS/l (limit = 30 mg SS/l)

Effluent average Kjeldahl N conc = 4.5046 mg N/l
Effluent average total N conc = 16.9245 mg N/l (limit = 18 mg COD/l)
Effluent average total COD conc = 48.2201 mg COD/l (limit = 100 mg COD/l)
Effluent average BOD5 conc = 2.7568 mg/l (limit = 10 mg/l)

Effluent average load

Effluent average SI load = 541.7363 kg COD/day
Effluent average SS load = 15.923 kg COD/day
Effluent average XI load = 82.5745 kg COD/day
Effluent average XS load = 3.6267 kg COD/day
Effluent average XBH load = 184.7574 kg COD/day
Effluent average XBA load = 10.438 kg COD/day

```
Effluent average XP load = 31.6976 kg COD/day
Effluent average SO load = 35.9017 kg (-COD)/day
Effluent average SNO load = 224.2771 kg N/day
Effluent average SNH load = 45.8525 kg N/day
Effluent average SND load = 12.7581 kg N/day
Effluent average XND load = 0.26039 kg N/day
Effluent average SALK load = 72.9708 kmol HCO3/day
Effluent average TSS load = 234.8206 kg SS/day

Effluent average Kjeldahl N load = 81.3429 kg N/d
Effluent average total N load = 305.6201 kg N/d
Effluent average total COD load = 870.7534 kg COD/d
Effluent average BOD5 load = 49.7823 kg/d

Other effluent quality variables
--------------------------------
Influent Quality (I.Q.) index = 42042.8149 kg poll.units/d (original BSM1
version)
Effluent Quality (E.Q.) index = 7552.3603 kg poll.units/d (original BSM1
version)
Influent Quality (I.Q.) index = 52081.3952 kg poll.units/d (updated BSM1
version)
Effluent Quality (E.Q.) index = 6123.0182 kg poll.units/d (updated BSM1
version)

Sludge production for disposal = 17084.2395 kg SS
Average sludge production for disposal per day = 2440.6056 kg SS/d
Sludge production released into effluent = 1643.744 kg SS
Average sludge production released into effluent per day = 234.8206 kg SS/d
Total sludge production = 18727.9835 kg SS
Total average sludge production per day = 2675.4262 kg SS/d

Total aeration energy = 50689.5466 kWh (original BSM1 version)
Average aeration energy per day = 7241.3638 kWh/d (original BSM1 version)
Total aeration energy = 25888.4069 kWh (updated BSM1 version)
Average aeration energy per day = 3698.3438 kWh/d (updated BSM1 version)

Total pumping energy (for Qintr, Qr and Qw) = 10467.5555 kWh (original BSM1
version)
Average pumping energy per day (for Qintr, Qr and Qw) = 1495.3651 kWh/d
(original BSM1 version)
Total pumping energy (for Qintr, Qr and Qw) = 1687.2136 kWh (based on BSM2
principles)
Average pumping energy per day (for Qintr, Qr and Qw) = 241.0305 kWh/d
(based on BSM2 principles)

Total mixing energy = 1680 kWh (based on BSM2 principles)
Average mixing energy per day = 240 kWh/d (based on BSM2 principles)

Total added carbon volume = 0 m3
Average added carbon flow rate = 0 m3/d
Total added carbon mass = 0 kg COD
Average added carbon mass per day = 0 kg COD/d

Operational Cost Index
----------------------
Sludge production cost index = 12203.0282 (using weight 5 for BSM1)
Aeration energy cost index = 7241.3638 (original BSM1 version)
Updated aeration energy cost index = 3698.3438 (updated BSM1 version)
Pumping energy cost index = 1495.3651 (original BSM1 version)
Updated pumping energy cost index = 241.0305 (based on BSM2 principles)
Carbon source addition cost index = 0
Mixing energy cost index = 240 (based on BSM2 principles)
```

Total Operational Cost Index (OCI) = 21179.7571 (original BSM1 version)
Updated Total Operational Cost Index (OCI) = 16382.4026 (using new aeraration and pumping costs)

Effluent violations

95% percentile for effluent SNH (Ammonia95) = 7.3902 g N/m3
95% percentile for effluent TN (TN95) = 20.2693 g N/m3
95% percentile for effluent TSS (TSS95) = 15.7663 g SS/m3

The maximum effluent total nitrogen level (18 mg N/l) was violated during 1.2813 days, i.e. 18.3036% of the operating time.
The limit was violated at 7 different occasions.

The maximum effluent ammonia nitrogen level (4 mg N/l) was violated during 1.1979 days, i.e. 17.1131% of the operating time.
The limit was violated at 5 different occasions.

Qualitative criteria for settling problems

The plant has experienced high (>0.8) risk for the development of filamentous bulking due to N deficiency
during 0 days, i.e. 0% of the operating time.
...and risk for the development of filamentous bulking due to N deficiency 100% of the operating time.
average risk 0.00011765

The plant has experienced high (>0.8) risk for the development of aerobic (low DO) filamentous bulking
during 0.57292 days, i.e. 8.1845% of the operating time.
...and risk for the development of aerobic (low DO) filamentous bulking 97.4702% of the operating time.
average risk 0.33851
The most dangerous situation was between days 8.4479 and 8.5729

The plant has experienced severe (>0.8) risk for the development of low F/M filamentous bulking
during 3 days, i.e. 42.8571% of the operating time.
...and risk for the development of low F/M filamentous bulking 100% of the operating time.
average risk 0.73513
The most dangerous situation was between days 13 and 13.4375

The plant has experienced high (>0.8) risk for the development of low F/M foaming
during 0 days, i.e. 0% of the operating time.
...and risk for the development of low F/M foaming 100% of the operating time.
average risk 0.53998

The plant has experienced high (>0.8) risk for the development of foaming due to high Ss/Xs fraction
during 0 days, i.e. 0% of the operating time.
...and risk for the development of foaming due to high Ss/Xs fraction 99.7024% of the operating time.
average risk 0.025851

The plant has experienced high (>0.8) risk for the development of rising sludge
during 4 days, i.e. 57.1429% of the operating time.
...and risk for the development of rising sludge 100% of the operating time.
average risk 0.70072

```
The most dangerous situation was between days 9.4479 and 10.1563

Overall risk
------------
The plant has experienced severe (>0.8) risk for (integrated) BULKING
during 3.5729 days, i.e. 51.0417% of the operating time.
...and risk for the development of (integrated) Bulking 100% of the
operating time.
average risk 0.81085
The most dangerous situation was between days 13 and 13.4375

The plant has experienced severe (>0.8) risk for (integrated) FOAMING
during 0 days, i.e. 0% of the operating time.
...and risk for the development of (integrated) Foaming 100% of the
operating time.
average risk 0.5489

The plant has experienced high (>0.8) risk for the development of RISING
SLUDGE
during 4 days, i.e. 57.1429% of the operating time.
...and risk for the development of rising sludge 100% of the operating
time.
average risk 0.70072
The most dangerous situation was between days 9.4479 and 10.1563

The plant has experienced OVERALL severe (>0.8) risk for OVERALL SETTLING
PROBLEMS
during 6.5625 days, i.e. 93.75% of the operating time.
...and risk for the development of OVERALL SETTLING PROBLEMS 100% of the
operating time.
average risk 0.97423
The most dangerous situation was between days 8.0313 and 12.4375

Performance of active controllers during time 7 to 14 days
**********************************************************

Nitrate controller for second anoxic reactor
============================================

PI controller with anti-windup: K = 10000 m3/d/(g N/m3)
                                Ti = 0.025 days
                                Tt = 0.015 days

Controlled variable - SNO (tank 2), setpoint = 1 mg N/l
-------------------------------------------------------
Average value of error (mean(e)) = -0.0021211 (mg N/l)
Average value of absolute error (mean(|e|)) = 0.20497 (mg N/l)
Integral of absolute error (IAE) = 1.4348 (mg N/l)*d
Integral of square error (ISE) = 0.56897 (mg N/l)^2*d
Maximum absolute deviation from nitrate setpoint (max(e)) = 0.91782 mg N/l
Standard deviation of error (std(e)) = 0.28509 mg N/l
Variance of error (var(e)) = 0.081276 (mg N/l)^2

Manipulated variable (MV), Qintr
--------------------------------
Maximum absolute variation of MV (max-min) = 45734.3961 m3/d
Maximum absolute variation of MV in one sample (max delta) = 18918.94 m3/d
Average value of MV (mean(Qintr)) = 18610.0823 m3/d
Standard deviation of MV (std(delta(Qintr))) = 4078.4756 m3/d
Variance of MV (var(delta(Qintr))) = 16633963.3767 (m3/d)^2


Oxygen controller for last aerobic reactor
```

```
=========================================

PI controller with anti-windup: K = 25 1/d/(g (-COD)/m3)
                                Ti = 0.002 days
                                Tt = 0.001 days

Controlled variable - SO (tank 5), setpoint = 2 mg (-COD)/l
-----------------------------------------------------------

Average value of error (mean(e)) = -0.00039763 (mg (-COD)/l)
Average value of absolute error (mean(|e|)) = 0.084044 (mg (-COD)/l)
Integral of absolute error (IAE) = 0.58831 (mg (-COD)/l)*d
Integral of square error (ISE) = 0.083975 (mg (-COD)/l)^2*d
Maximum absolute deviation from oxygen setpoint (max(e)) = 0.39631 mg (-
COD)/l
Standard deviation of error (std(e)) = 0.10953 mg (-COD)/l
Variance of error (var(e)) = 0.011996 (mg (-COD)/l)^2

Manipulated variable (MV), KLa (tank 5)
---------------------------------------
Based on KLa controller output prior to KLa actuator model
Maximum absolute variation of MV (max-min) = 242.2831 1/d
Maximum absolute variation of MV in one sample (max delta) = 47.8828 1/d
Average value of MV (mean(KLa5)) = 144.1219 1/d
Standard deviation of MV (std(delta(KLa5))) = 9.5682 1/d
Variance of MV (var(delta(KLa5))) = 91.5507 (1/d)^2
```

```
*********************
* RAINWEATHER FILE *
*********************

Overall plant performance during time 7 to 14 days
***************************************************

Effluent average concentrations based on load
---------------------------------------------
Effluent average flow rate = 23806.8789 m3/d
Effluent average SI conc = 22.8353 mg COD/l
Effluent average SS conc = 1.0294 mg COD/l
Effluent average XI conc = 5.6285 mg COD/l
Effluent average XS conc = 0.31107 mg COD/l
Effluent average XBH conc = 12.8824 mg COD/l
Effluent average XBA conc = 0.68536 mg COD/l
Effluent average XP conc = 2.0617 mg COD/l
Effluent average SO conc = 1.9918 mg (-COD)/l
Effluent average SNO conc = 9.1649 mg N/l
Effluent average SNH conc = 3.226 mg N/l  (limit = 4 mg N/l)
Effluent average SND conc = 0.78728 mg N/l
Effluent average XND conc = 0.021515 mg N/l
Effluent average SALK conc = 4.8606 mol HCO3/m3
Effluent average TSS conc = 16.1768 mg SS/l  (limit = 30 mg SS/l)

Effluent average Kjeldahl N conc = 5.5816 mg N/l
Effluent average total N conc = 14.7465 mg N/l  (limit = 18 mg COD/l)
Effluent average total COD conc = 45.4337 mg COD/l  (limit = 100 mg COD/l)
Effluent average BOD5 conc = 3.4557 mg/l  (limit = 10 mg/l)

Effluent average load
---------------------
Effluent average SI load = 543.6382 kg COD/day
Effluent average SS load = 24.5064 kg COD/day
Effluent average XI load = 133.9972 kg COD/day
Effluent average XS load = 7.4056 kg COD/day
Effluent average XBH load = 306.6892 kg COD/day
Effluent average XBA load = 16.3163 kg COD/day
Effluent average XP load = 49.0825 kg COD/day
Effluent average SO load = 47.4177 kg (-COD)/day
Effluent average SNO load = 218.1877 kg N/day
Effluent average SNH load = 76.8013 kg N/day
Effluent average SND load = 18.7426 kg N/day
Effluent average XND load = 0.5122 kg N/day
Effluent average SALK load = 115.7154 kmol HCO3/day
Effluent average TSS load = 385.118 kg SS/day

Effluent average Kjeldahl N load = 132.8813 kg N/d
Effluent average total N load = 351.069 kg N/d
Effluent average total COD load = 1081.6354 kg COD/d
Effluent average BOD5 load = 82.2692 kg/d

Other effluent quality variables
--------------------------------
Influent Quality (I.Q.) index = 42042.8149 kg poll.units/d (original BSM1
version)
Effluent Quality (E.Q.) index = 9037.7895 kg poll.units/d (original BSM1
version)
Influent Quality (I.Q.) index = 52081.3952 kg poll.units/d (updated BSM1
version)
Effluent Quality (E.Q.) index = 8184.7262 kg poll.units/d (updated BSM1
version)
```

Sludge production for disposal = 16503.1038 kg SS
Average sludge production for disposal per day = 2357.5863 kg SS/d
Sludge production released into effluent = 2695.8262 kg SS
Average sludge production released into effluent per day = 385.118 kg SS/d
Total sludge production = 19198.93 kg SS
Total average sludge production per day = 2742.7043 kg SS/d

Total aeration energy = 50195.1857 kWh (original BSM1 version)
Average aeration energy per day = 7170.7408 kWh/d (original BSM1 version)
Total aeration energy = 25699.4632 kWh (updated BSM1 version)
Average aeration energy per day = 3671.3519 kWh/d (updated BSM1 version)

Total pumping energy (for Qintr, Qr and Qw) = 13563.9015 kWh (original BSM1 version)
Average pumping energy per day (for Qintr, Qr and Qw) = 1937.7002 kWh/d (original BSM1 version)
Total pumping energy (for Qintr, Qr and Qw) = 1996.8482 kWh (based on BSM2 principles)
Average pumping energy per day (for Qintr, Qr and Qw) = 285.264 kWh/d (based on BSM2 principles)

Total mixing energy = 1680 kWh (based on BSM2 principles)
Average mixing energy per day = 240 kWh/d (based on BSM2 principles)

Total added carbon volume = 0 m3
Average added carbon flow rate = 0 m3/d
Total added carbon mass = 0 kg COD
Average added carbon mass per day = 0 kg COD/d

Operational Cost Index

Sludge production cost index = 11787.9313 (using weight 5 for BSM1)
Aeration energy cost index = 7170.7408 (original BSM1 version)
Updated aeration energy cost index = 3671.3519 (updated BSM1 version)
Pumping energy cost index = 1937.7002 (original BSM1 version)
Updated pumping energy cost index = 285.264 (based on BSM2 principles)
Carbon source addition cost index = 0
Mixing energy cost index = 240 (based on BSM2 principles)
Total Operational Cost Index (OCI) = 21136.3723 (original BSM1 version)
Updated Total Operational Cost Index (OCI) = 15984.5472 (using new aeraration and pumping costs)

Effluent violations

95% percentile for effluent SNH (Ammonia95) = 8.0395 g N/m3
95% percentile for effluent TN (TN95) = 19.1429 g N/m3
95% percentile for effluent TSS (TSS95) = 21.6967 g SS/m3

The maximum effluent total nitrogen level (18 mg N/l) was violated
during 0.77083 days, i.e. 11.0119% of the operating time.
The limit was violated at 5 different occasions.

The maximum effluent ammonia nitrogen level (4 mg N/l) was violated
during 1.8958 days, i.e. 27.0833% of the operating time.
The limit was violated at 8 different occasions.

Qualitative criteria for settling problems

The plant has experienced high (>0.8) risk for the development of filamentous bulking due to N deficiency
during 0 days, i.e. 0% of the operating time.
...and risk for the development of filamentous bulking due to N deficiency
100% of the operating time.

average risk 0.00011765

The plant has experienced high (>0.8) risk for the development of aerobic (low DO) filamentous bulking
during 0.73958 days, i.e. 10.5655% of the operating time.
...and risk for the development of aerobic (low DO) filamentous bulking 96.875% of the operating time.
average risk 0.29893
The most dangerous situation was between days 8.4583 and 8.6146

The plant has experienced severe (>0.8) risk for the development of low F/M filamentous bulking
during 2.8542 days, i.e. 40.7738% of the operating time.
...and risk for the development of low F/M filamentous bulking 100% of the operating time.
average risk 0.68295
The most dangerous situation was between days 12.0104 and 12.4375

The plant has experienced high (>0.8) risk for the development of low F/M foaming
during 0 days, i.e. 0% of the operating time.
...and risk for the development of low F/M foaming 100% of the operating time.
average risk 0.42182

The plant has experienced high (>0.8) risk for the development of foaming due to high Ss/Xs fraction
during 0 days, i.e. 0% of the operating time.
...and risk for the development of foaming due to high Ss/Xs fraction 99.5536% of the operating time.
average risk 0.050795

The plant has experienced high (>0.8) risk for the development of rising sludge
during 2.375 days, i.e. 33.9286% of the operating time.
...and risk for the development of rising sludge 100% of the operating time.
average risk 0.64257
The most dangerous situation was between days 7.4479 and 8.1458

Overall risk

The plant has experienced severe (>0.8) risk for (integrated) BULKING
during 3.5938 days, i.e. 51.3393% of the operating time.
...and risk for the development of (integrated) Bulking 100% of the operating time.
average risk 0.78821
The most dangerous situation was between days 12.0104 and 12.4375

The plant has experienced severe (>0.8) risk for (integrated) FOAMING
during 0 days, i.e. 0% of the operating time.
...and risk for the development of (integrated) Foaming 100% of the operating time.
average risk 0.45421

The plant has experienced high (>0.8) risk for the development of RISING SLUDGE
during 2.375 days, i.e. 33.9286% of the operating time.
...and risk for the development of rising sludge 100% of the operating time.
average risk 0.64257
The most dangerous situation was between days 7.4479 and 8.1458

The plant has experienced OVERALL severe (>0.8) risk for OVERALL SETTLING PROBLEMS
during 5.375 days, i.e. 76.7857% of the operating time.
...and risk for the development of OVERALL SETTLING PROBLEMS 100% of the operating time.
average risk 0.90442
The most dangerous situation was between days 8.0208 and 12.4375

Performance of active controllers during time 7 to 14 days
****

Nitrate controller for second anoxic reactor
==========

PI controller with anti-windup: K = 10000 m3/d/(g N/m3)
Ti = 0.025 days
Tt = 0.015 days

Controlled variable - SNO (tank 2), setpoint = 1 mg N/l

Average value of error (mean(e)) = 0.002672 (mg N/l)
Average value of absolute error (mean(|e|)) = 0.24784 (mg N/l)
Integral of absolute error (IAE) = 1.7349 (mg N/l)*d
Integral of square error (ISE) = 0.79436 (mg N/l)^2*d
Maximum absolute deviation from nitrate setpoint (max(e)) = 0.92134 mg N/l
Standard deviation of error (std(e)) = 0.33686 mg N/l
Variance of error (var(e)) = 0.11347 (mg N/l)^2

Manipulated variable (MV), Qintr

Maximum absolute variation of MV (max-min) = 84374.4058 m3/d
Maximum absolute variation of MV in one sample (max delta) = 18678.4397 m3/d
Average value of MV (mean(Qintr)) = 29608.9369 m3/d
Standard deviation of MV (std(delta(Qintr))) = 4110.5486 m3/d
Variance of MV (var(delta(Qintr))) = 16896609.9786 (m3/d)^2

Oxygen controller for last aerobic reactor
==========

PI controller with anti-windup: K = 25 1/d/(g (-COD)/m3)
Ti = 0.002 days
Tt = 0.001 days

Controlled variable - SO (tank 5), setpoint = 2 mg (-COD)/l

Average value of error (mean(e)) = -0.00046529 (mg (-COD)/l)
Average value of absolute error (mean(|e|)) = 0.079532 (mg (-COD)/l)
Integral of absolute error (IAE) = 0.55672 (mg (-COD)/l)*d
Integral of square error (ISE) = 0.074733 (mg (-COD)/l)^2*d
Maximum absolute deviation from oxygen setpoint (max(e)) = 0.38505 mg (-COD)/l
Standard deviation of error (std(e)) = 0.10332 mg (-COD)/l
Variance of error (var(e)) = 0.010676 (mg (-COD)/l)^2

Manipulated variable (MV), KLa (tank 5)

Based on KLa controller output prior to KLa actuator model
Maximum absolute variation of MV (max-min) = 227.3181 1/d
Maximum absolute variation of MV in one sample (max delta) = 47.8828 1/d

Average value of MV (mean(KLa5)) = 139.5768 1/d
Standard deviation of MV (std(delta(KLa5))) = 9.2235 1/d
Variance of MV (var(delta(KLa5))) = 85.0722 (1/d)^2

```
**********************
* STORMWEATHER FILE *
**********************

Overall plant performance during time 7 to 14 days
***********************************************

Effluent average concentrations based on load
---------------------------------------------
Effluent average flow rate = 20654.9629 m3/d
Effluent average SI conc = 26.2982 mg COD/l
Effluent average SS conc = 0.9995 mg COD/l
Effluent average XI conc = 5.6341 mg COD/l
Effluent average XS conc = 0.28755 mg COD/l
Effluent average XBH conc = 11.9051 mg COD/l
Effluent average XBA conc = 0.63091 mg COD/l
Effluent average XP conc = 1.9072 mg COD/l
Effluent average SO conc = 1.9905 mg (-COD)/l
Effluent average SNO conc = 10.553 mg N/l
Effluent average SNH conc = 3.0622 mg N/l  (limit = 4 mg N/l)
Effluent average SND conc = 0.77656 mg N/l
Effluent average XND conc = 0.02043 mg N/l
Effluent average SALK conc = 4.4897 mol HCO3/m3
Effluent average TSS conc = 15.2737 mg SS/l  (limit = 30 mg SS/l)

Effluent average Kjeldahl N conc = 5.3146 mg N/l
Effluent average total N conc = 15.8676 mg N/l  (limit = 18 mg COD/l)
Effluent average total COD conc = 47.6626 mg COD/l  (limit = 100 mg COD/l)
Effluent average BOD5 conc = 3.205 mg/l  (limit = 10 mg/l)

Effluent average load
---------------------
Effluent average SI load = 543.1883 kg COD/day
Effluent average SS load = 20.6447 kg COD/day
Effluent average XI load = 116.372 kg COD/day
Effluent average XS load = 5.9394 kg COD/day
Effluent average XBH load = 245.8993 kg COD/day
Effluent average XBA load = 13.0314 kg COD/day
Effluent average XP load = 39.3935 kg COD/day
Effluent average SO load = 41.1136 kg (-COD)/day
Effluent average SNO load = 217.9728 kg N/day
Effluent average SNH load = 63.2503 kg N/day
Effluent average SND load = 16.0398 kg N/day
Effluent average XND load = 0.42198 kg N/day
Effluent average SALK load = 92.7345 kmol HCO3/day
Effluent average TSS load = 315.4767 kg SS/day

Effluent average Kjeldahl N load = 109.7725 kg N/d
Effluent average total N load = 327.7453 kg N/d
Effluent average total COD load = 984.4686 kg COD/d
Effluent average BOD5 load = 66.2001 kg/d

Other effluent quality variables
--------------------------------
Influent Quality (I.Q.) index = 43758.1149 kg poll.units/d (original BSM1
version)
Effluent Quality (E.Q.) index = 8302.7276 kg poll.units/d (original BSM1
version)
Influent Quality (I.Q.) index = 54061.497 kg poll.units/d (updated BSM1
version)
Effluent Quality (E.Q.) index = 7220.724 kg poll.units/d (updated BSM1
version)
```

Sludge production for disposal = 18238.4309 kg SS
Average sludge production for disposal per day = 2605.4901 kg SS/d
Sludge production released into effluent = 2208.337 kg SS
Average sludge production released into effluent per day = 315.4767 kg SS/d
Total sludge production = 20446.768 kg SS
Total average sludge production per day = 2920.9669 kg SS/d

Total aeration energy = 51024.3581 kWh (original BSM1 version)
Average aeration energy per day = 7289.194 kWh/d (original BSM1 version)
Total aeration energy = 26046.4215 kWh (updated BSM1 version)
Average aeration energy per day = 3720.9174 kWh/d (updated BSM1 version)

Total pumping energy (for Qintr, Qr and Qw) = 12159.3062 kWh (original BSM1 version)
Average pumping energy per day (for Qintr, Qr and Qw) = 1737.0437 kWh/d (original BSM1 version)
Total pumping energy (for Qintr, Qr and Qw) = 1856.3886 kWh (based on BSM2 principles)
Average pumping energy per day (for Qintr, Qr and Qw) = 265.1984 kWh/d (based on BSM2 principles)

Total mixing energy = 1680 kWh (based on BSM2 principles)
Average mixing energy per day = 240 kWh/d (based on BSM2 principles)

Total added carbon volume = 0 m3
Average added carbon flow rate = 0 m3/d
Total added carbon mass = 0 kg COD
Average added carbon mass per day = 0 kg COD/d

Operational Cost Index

Sludge production cost index = 13027.4507 (using weight 5 for BSM1)
Aeration energy cost index = 7289.194 (original BSM1 version)
Updated aeration energy cost index = 3720.9174 (updated BSM1 version)
Pumping energy cost index = 1737.0437 (original BSM1 version)
Updated pumping energy cost index = 265.1984 (based on BSM2 principles)
Carbon source addition cost index = 0
Mixing energy cost index = 240 (based on BSM2 principles)
Total Operational Cost Index (OCI) = 22293.6884 (original BSM1 version)
Updated Total Operational Cost Index (OCI) = 17253.5664 (using new aeraration and pumping costs)

Effluent violations

95% percentile for effluent SNH (Ammonia95) = 7.8033 g N/m3
95% percentile for effluent TN (TN95) = 20.1257 g N/m3
95% percentile for effluent TSS (TSS95) = 20.7886 g SS/m3

The maximum effluent total nitrogen level (18 mg N/l) was violated during 1.0938 days, i.e. 15.625% of the operating time.
The limit was violated at 7 different occasions.

The maximum effluent ammonia nitrogen level (4 mg N/l) was violated during 1.8854 days, i.e. 26.9345% of the operating time.
The limit was violated at 7 different occasions.

The maximum effluent total suspended solids level (30 mg SS/l) was violated during 0.020833 days, i.e. 0.29762% of the operating time.
The limit was violated at 2 different occasions.

Qualitative criteria for settling problems

The plant has experienced high (>0.8) risk for the development of filamentous bulking due to N deficiency
during 0 days, i.e. 0% of the operating time.
...and risk for the development of filamentous bulking due to N deficiency 100% of the operating time.
average risk 0.00011765

The plant has experienced high (>0.8) risk for the development of aerobic (low DO) filamentous bulking
during 0.83333 days, i.e. 11.9048% of the operating time.
...and risk for the development of aerobic (low DO) filamentous bulking 96.2798% of the operating time.
average risk 0.32587
The most dangerous situation was between days 8.4479 and 8.5729

The plant has experienced severe (>0.8) risk for the development of low F/M filamentous bulking
during 2.9792 days, i.e. 42.5595% of the operating time.
...and risk for the development of low F/M filamentous bulking 100% of the operating time.
average risk 0.72582
The most dangerous situation was between days 13 and 13.4375

The plant has experienced high (>0.8) risk for the development of low F/M foaming
during 0 days, i.e. 0% of the operating time.
...and risk for the development of low F/M foaming 100% of the operating time.
average risk 0.50246

The plant has experienced high (>0.8) risk for the development of foaming due to high Ss/Xs fraction
during 0 days, i.e. 0% of the operating time.
...and risk for the development of foaming due to high Ss/Xs fraction 99.1071% of the operating time.
average risk 0.034889

The plant has experienced high (>0.8) risk for the development of rising sludge
during 3.5625 days, i.e. 50.8929% of the operating time.
...and risk for the development of rising sludge 100% of the operating time.
average risk 0.69682
The most dangerous situation was between days 9.4479 and 10.1667

Overall risk

The plant has experienced severe (>0.8) risk for (integrated) BULKING
during 3.8125 days, i.e. 54.4643% of the operating time.
...and risk for the development of (integrated) Bulking 100% of the operating time.
average risk 0.81829
The most dangerous situation was between days 13 and 13.4375

The plant has experienced severe (>0.8) risk for (integrated) FOAMING
during 0 days, i.e. 0% of the operating time.
...and risk for the development of (integrated) Foaming 100% of the operating time.
average risk 0.517

The plant has experienced high (>0.8) risk for the development of RISING SLUDGE
during 3.5625 days, i.e. 50.8929% of the operating time.

...and risk for the development of rising sludge 100% of the operating time.
average risk 0.69682
The most dangerous situation was between days 9.4479 and 10.1667

The plant has experienced OVERALL severe (>0.8) risk for OVERALL SETTLING PROBLEMS
during 6.3021 days, i.e. 90.0298% of the operating time.
...and risk for the development of OVERALL SETTLING PROBLEMS 100% of the operating time.
average risk 0.9588
The most dangerous situation was between days 8.0208 and 10.4271

Performance of active controllers during time 7 to 14 days
****

Nitrate controller for second anoxic reactor
==========

PI controller with anti-windup: K = 10000 m3/d/(g N/m3)
Ti = 0.025 days
Tt = 0.015 days

Controlled variable - SNO (tank 2), setpoint = 1 mg N/l

Average value of error (mean(e)) = 0.0051026 (mg N/l)
Average value of absolute error (mean(|e|)) = 0.23979 (mg N/l)
Integral of absolute error (IAE) = 1.6785 (mg N/l)*d
Integral of square error (ISE) = 0.78797 (mg N/l)^2*d
Maximum absolute deviation from nitrate setpoint (max(e)) = 1.2014 mg N/l
Standard deviation of error (std(e)) = 0.33547 mg N/l
Variance of error (var(e)) = 0.11254 (mg N/l)^2

Manipulated variable (MV), Qintr

Maximum absolute variation of MV (max-min) = 83663.6737 m3/d
Maximum absolute variation of MV in one sample (max delta) = 18489.0489 m3/d
Average value of MV (mean(Qintr)) = 24623.0359 m3/d
Standard deviation of MV (std(delta(Qintr))) = 4141.7466 m3/d
Variance of MV (var(delta(Qintr))) = 17154064.6172 (m3/d)^2

Oxygen controller for last aerobic reactor
==========

PI controller with anti-windup: K = 25 1/d/(g (-COD)/m3)
Ti = 0.002 days
Tt = 0.001 days

Controlled variable - SO (tank 5), setpoint = 2 mg (-COD)/l

Average value of error (mean(e)) = -0.00038723 (mg (-COD)/l)
Average value of absolute error (mean(|e|)) = 0.080854 (mg (-COD)/l)
Integral of absolute error (IAE) = 0.56598 (mg (-COD)/l)*d
Integral of square error (ISE) = 0.078876 (mg (-COD)/l)^2*d
Maximum absolute deviation from oxygen setpoint (max(e)) = 0.37924 mg (-COD)/l
Standard deviation of error (std(e)) = 0.10615 mg (-COD)/l
Variance of error (var(e)) = 0.011268 (mg (-COD)/l)^2

Manipulated variable (MV), KLa (tank 5)

Based on KLa controller output prior to KLa actuator model
Maximum absolute variation of MV (max-min) = 244.5373 1/d
Maximum absolute variation of MV in one sample (max delta) = 47.8829 1/d
Average value of MV (mean(KLa5)) = 147.9338 1/d
Standard deviation of MV (std(delta(KLa5))) = 9.3809 1/d
Variance of MV (var(delta(KLa5))) = 88.0009 (1/d)^2