Multi-criteria evaluation of control strategies in WWTP

Xavier Flores-Alsina, Lluis Corominas, Peter A. Vanrolleghem

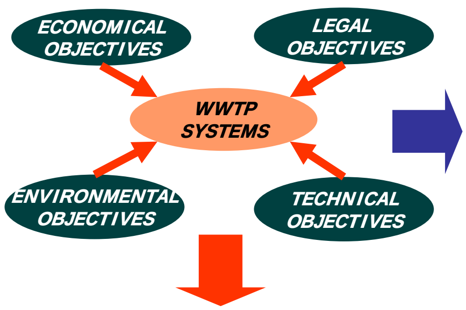
Neptune workshop: Technical Solutions for Nutrient and Micropollutants Removal in WWTPs
Université Laval, Québec, March 25-26, 2010

Overview

1. Introduction
2. Plant Layout, Control Strategies and Evaluation Criteria
3. Multivariate Analysis Results
4. Conclusions

1. Introduction

***Evaluation** of control strategies on a WWTP is a **COMPLEX** activity due to the **LARGE** number of **OBJECTIVES** that have to be taken into account*



The accomplishment of those objectives generates significant SYNERGIES but is in many cases subjected to clear TRADE-OFFS

MULTI-CRITERIA DECISION PROBLEM

1. Introduction

The result is a huge and complex evaluation matrix

WHICH IS OFTEN DIFFICULT TO INTERPRET, HENCE DIFFICULT TO DRAW MEANINGFUL CONCLUSIONS

Nevertheless this process could be improved with

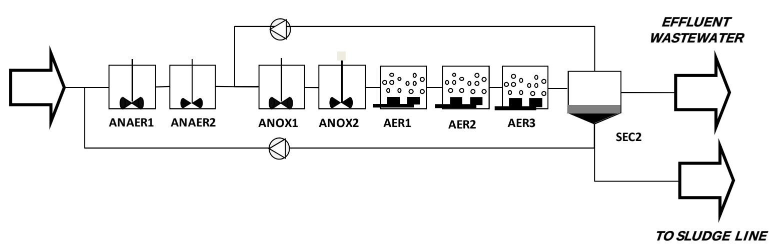
- ***Efficient tools to discover groups of control strategies***
- ***Facilitating the interpretation of the complex interactions amongst multiple criteria***
- ***Identifying the main features of a specific control or a group of control strategies***

Overview

1. Introduction
2. Plant Layout, Control Strategies and Evaluation Criteria
3. Multivariate Analysis Results
4. Conclusions

2. Plant layout, control strategies and evaluation criteria

- A2O plant sized using Metcalf & Eddy design guidelines



- The influent profile has been generated using phenomenological models including daily, weekly and seasonal variation
- The EAWAG ASM3 bio P and the double exponential velocity function of Takács are the main process models

2. Plant layout, control strategies and evaluation criteria

controller	Measured Variable	Manipulated Variable	Control algorithm	Initial value
DO conroller	SO in AER	$k_L a$ (airflow)	PI	2 g m^{-3}
SNH controller	SNH in AER	DO setpoint	Cascaded PI	2 g m^{-3}
SNO controller	SNO in ANOX	Qintr	PI	1 g m^{-3}
SNO controller	SNO in ANOX	Qcarb	PI	1 g m^{-3}
TSS controller	TSS in AER	Qwaste	cascaded PI	If T> 15 C 2500 g m^{-3} If T < 15 C 3500 g m^{-3}
SPO controller	SPO in AER	Qmetal	PI	2 g m^{-3}
OUR controller	OUR in AER	DO setpoint	Cascaded ON/OFF	1850 g $m^{-3}d^{-1}$

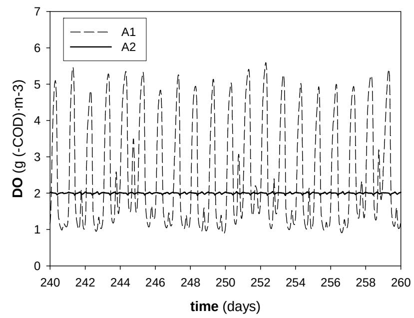
2. Plant layout, control strategies and evaluation criteria

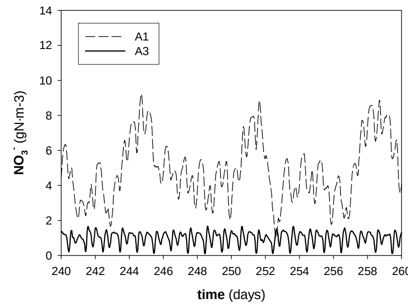
- Effluent quality index (EQI)

$$EQI = \frac{1}{t.1000}\int_{to}^{tf} (PU_{TSS} + PU_{BOD} + PU_{COD} + PU_{TKN} + PU_{NO} + PU_{TP}) \cdot Q \cdot dt$$

- Operational cost index (OCI)

$$OCI = SP + AE + PE + ME + CHEM$$





DO controller

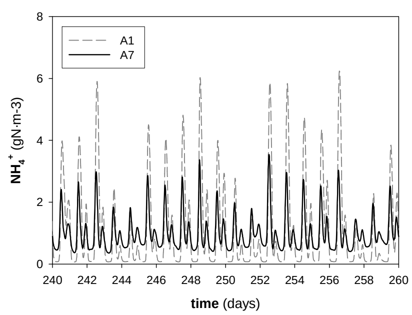
Improve EQI

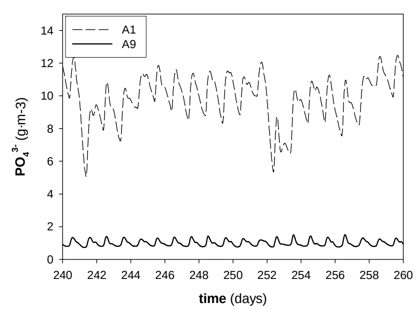
Decrease OCI (AE)

NO controller

Improve EQI

Decrease OCI (PE)





NH4 controller

Improve EQI

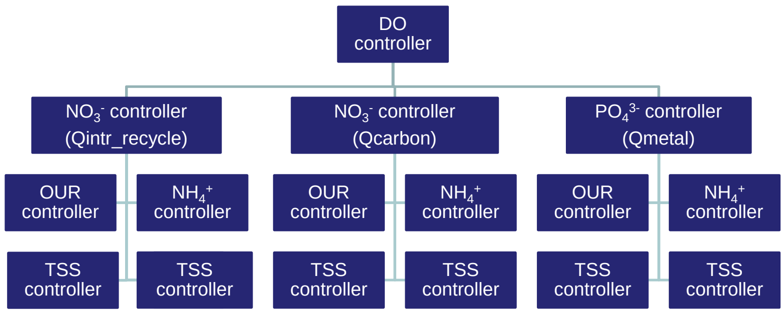
Decrease OCI (AE)

Qmetal controller

Improve EQI

Increase OCI (IRON, SP)

2. Plant layout, control strategies and evaluation criteria



2. Plant layout, control strategies and evaluation criteria

What happens when the evaluation procedure is upagraded with adddditional 24 criteria? i.e. technical, environmental, legal……

		DO	DO+Qi	DO+Qi+SNH	+QI+SNH+TSS	DO+Qc	DO+Qc+SNH	Qc+SNH+TSS	DO+Qm	DO+Qm+SNH	Qm+SNH+TSS	DO+Qi+OUR	QI+OUR+TSS	DO+Qc+OUR	)+QI+Qc+TSS	DO+Qm+OUR	Qm+SNH+TSS
TKNeav	3.40	3.18	2.87	2.98	3.07	3.37	3.39	4.05	3.18	3.12	3.36	2.87	2.89	3.35	4.64	3.29	3.86
TNeav	13.19	12.99	12.71	11.48	11.26	9.25	8.66	9.44	12.88	11.94	11.87	12.42	12.61	9.27	10.15	12.37	12.74
TPeav	9.47	9.48	9.09	8.15	8.02	5.73	5.31	5.84	1.20	1.19	1.19	8.88	8.86	5.77	5.58	1.19	1.18
SPO4eav	9.27	9.29	8.89	7.95	7.82	5.49	5.06	5.64	1.01	1.01	1.00	8.68	8.66	5.53	5.38	1.00	0.99
TCODeav	55.07	55.09	54.98	54.93	55.44	58.56	59.11	55.07	54.20	54.24	54.42	54.97	55.77	58.49	55.10	54.22	54.45
BOD5eav	1.58	1.59	1.60	1.67	1.68	2.27	2.40	1.93	1.51	1.57	1.58	1.62	1.58	2.26	1.93	1.54	1.53
XTSSav	16.02	16.03	16.12	16.40	16.99	20.33	21.07	16.96	16.60	16.75	16.98	16.19	16.99	20.27	16.95	16.69	16.98
EQI	**14040.00**	**13906.00**	**13432.00**	**12590.00**	**12579.00**	**11098.00**	**10777.00**	**11060.00**	**8213.90**	**7984.30**	**8104.60**	**13235.00**	**13402.00**	**11113.00**	**11312.00**	**8150.40**	**8526.10**
TSSproducedperd	2558.60	2564.70	2604.60	2725.30	2686.70	3311.00	3332.70	3364.80	2813.70	2879.30	2880.50	2631.50	2534.30	3297.50	3450.80	2851.20	2837.80
airenergyperd	3844.70	3538.00	3537.70	3222.10	3199.30	4384.40	3942.80	3795.40	3539.50	3367.60	3334.00	3503.20	3575.00	4334.90	4130.10	3473.10	3471.90
pumpenergyperd	632.80	632.80	349.88	386.37	399.26	632.80	632.80	635.66	632.80	632.80	632.83	356.24	351.01	632.80	636.16	632.80	632.61
metalmass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3949.30	3615.90	3550.90	0.00	0.00	0.00	0.00	3766.40	3700.20
carbonmass	0.00	0.00	0.00	0.00	0.00	1785.90	1509.60	1184.90	0.00	0.00	0.00	0.00	0.00	2324.20	2099.00	0.00	0.00
mixenergyperd	600.19	600.19	600.19	601.10	601.17	600.19	600.62	600.88	600.19	601.37	601.42	637.68	630.70	607.73	610.72	655.82	649.29
OCI	**12754.00**	**12465.00**	**12302.00**	**12385.00**	**12260.00**	**20908.00**	**19703.00**	**18681.00**	**19137.00**	**18664.00**	**18536.00**	**12714.00**	**12489.00**	**22793.00**	**22376.00**	**19269.00**	**19128.00**
Nviolation	7.52	4.59	5.96	5.84	6.13	0.56	0.90	3.13	4.03	5.95	7.34	5.23	6.47	0.60	6.18	2.53	6.18
CODviolation	0.00	0.00	0.00	0.00	0.01	1.28	1.71	0.00	0.00	0.00	0.00	0.00	0.01	1.24	0.00	0.00	0.00
SNHviolation	20.04	16.21	12.97	9.10	10.19	16.24	11.80	22.62	16.83	11.94	15.51	12.54	13.43	16.03	30.14	17.20	22.92
TSSviolation	0.00	0.00	0.00	0.00	0.12	2.15	2.67	0.09	0.00	0.00	0.11	0.00	0.11	1.96	0.08	0.00	0.10
BOD5violation	0.00	0.00	0.00	0.00	0.17	2.87	3.66	0.34	0.00	0.00	0.11	0.00	0.11	2.81	0.31	0.00	0.10
Pviolation	100.00	100.00	100.00	99.89	99.88	83.82	83.31	90.38	0.00	1.15	1.68	100.00	100.00	84.95	84.41	0.57	2.12
NofNDefBulking1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NofLow DOBulking1	0.53	0.51	0.50	0.56	0.55	0.39	0.45	0.46	0.51	0.54	0.53	0.49	0.47	0.43	0.47	0.49	0.49
NofLow FtoMBulking	0.71	0.71	0.72	0.75	0.77	0.70	0.73	0.71	0.71	0.73	0.74	0.72	0.74	0.66	0.65	0.72	0.72

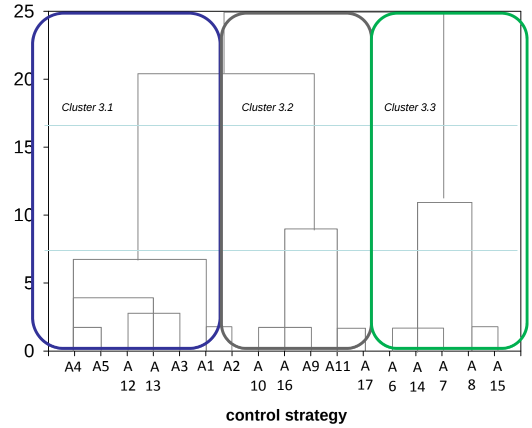
Overview

3. Multivariate analysis

- **Cluster analysis (CA)** : determine groups of control strategies with similar behaviour
- **Principal component analysis (PCA):** find hidden casual and complex relationships amongst data
- **Discriminant analysis (DA)** : identifies the most discriminant variables with the groups of controller identified by CA

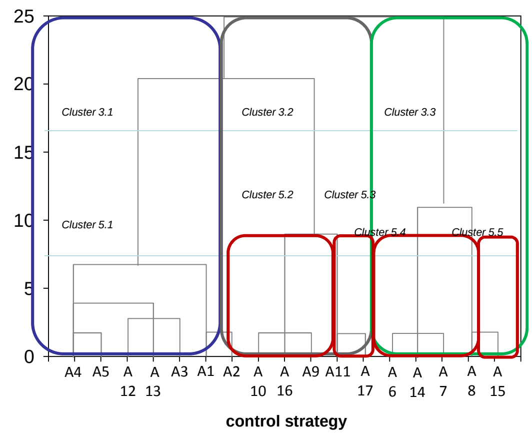
3. Multivariate analysis : CA

	DO CONTROLLER	AMMONIUM CONTROLLER	SURMACZ CONTROLLER	Qintr CONTROLLER	Qcarb CONTROLLER	Qmetal CONTROLLER	TSS CONTROLLER



3. Multivariate analysis : CA

	DO CONTROLLER	AMMONIUM CONTROLLER	SURMACZ CONTROLLER	Qintr CONTROLLER	Qcarb CONTROLLER	Qmetal CONTROLLER	TSS CONTROLLER



3. Multivariate analysis : PCA

- Total Kjeldahl Nitrogen (TKN)
- Total Nitrogen (TN)
- Total Phosphate (SPO4)
- Total Phosphorus concentration (TP)
- Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD5)
- Total Suspended Solids (TSS)
- Effluent Quality Index (EQI)
- Sludge Production (Psludge)
- Aeration Energy (AE)
- Pumping Energy (PE)
- Metal Salt Addition (MS)
- External Carbon Source (CS)
- Mixing Energy (ME)
- OCI
- Nviolation (L = 18 g m-3)
- CODviolation (L = 100 g m-3)
- SNHviolation L = 4 g m-3)
- TSSviolation (L = 30 g m-3)
- BOD5violation (L = 20 g m-3)
- Pviolation (L = 2 g m-3)
- N deficiency bulking
- DO deficiency bulking
- Low FMbulking

4 PRINCIPAL COMPONENT ARE EXTRACTED EXPLAINING 94 % OF THE TOTAL VARIABILITY

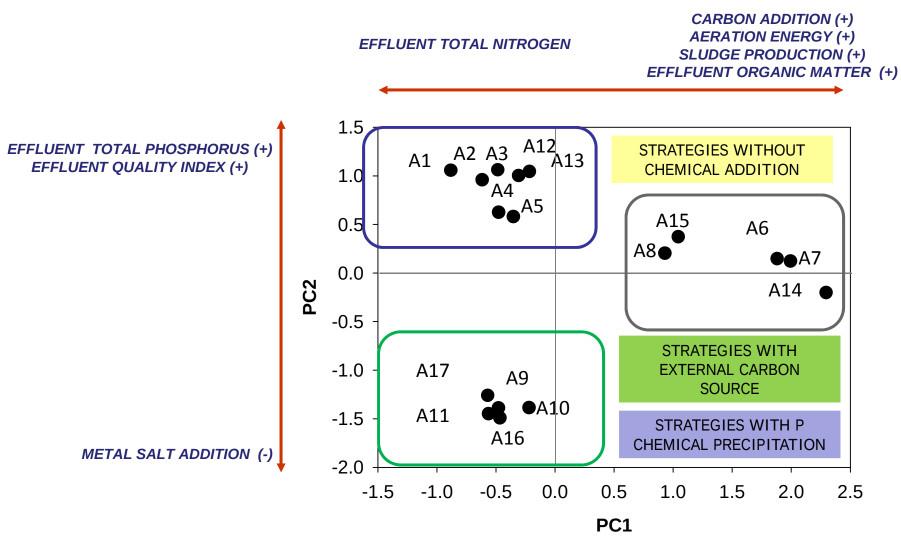
FIRST PC CORRELATES correlates effluent nitrogen negatively with external carbon source, aeration energy and sludge production

SECOND PC HIGHLIGHTS that only with the addition of metal low concentrations of P can be achieved

THIRD PC IS ASSOCIATED with high effluent ammonia values

FOURTH PC IS ASSCOCIATED with high mixing energy values

3. Multivariate analysis : PCA



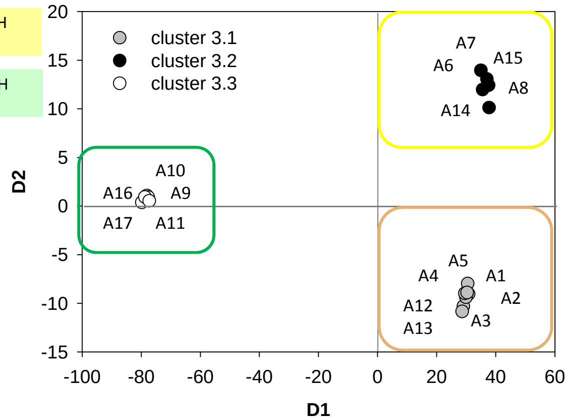
3. Multivariate analysis : DA

DISCRIMINANT ANALYSIS

CLUSTER 1: CONTROL STRATEGIES WITHOUT CHEMICAL ADDITION

CLUSTER 2: CONTROL STRATEGIES WITH EXTERNAL CARBON SOURCE ADDITION

CLUSTER 3: CONTROL STRATEGIES WITH PHOSPHORUS PRECIPITATION



DISCRIMIANT CRITERIA

SLUDGE PRODUCTION
AERATION ENERGY
COD VIOLATION
P VIOLATION

Overview

1. Introduction
2. Plant Layout, Control Strategies and Evaluation Criteria
3. Multivariate Analysis Results
4. Conclusions

4. Conclusions

- Control improve the overall performance of WWTP. Some of the presented controllers improve effluent quality, reduce operation costs or increase technical reliability
- There are complex interactions between the different criteria used to evaluate the presented controllers
- Multi-criteria/Multi-variable techniques are straightforward when characterizing control strategies

4. Conclusions

- Cluster analysis rendered five groups of control strategies and identified similar patterns in the controls strategies with and without chemical addition and/or TSS controller
- Principal component analysis reduced the complex evaluation matrix (24 criteria) to 4 variables. PCA also identified their main synergies and trade-offs.
- Discriminant analysis identified that only a small set of criteria create big differences between the groups created by CA

Acknowledgements

This research is supported by the Canada Research Chair in Water Quality Modeling and a NSERC Special Research Opportunities grant as part of the Canadian contribution to the European Union 6th framework project NEPTUNE. This study was part of the EU Neptune project (Contract No 036845, SUSTDEV-2005-3.II.3.2), which is financially supported by grants obtained from the EU Commission within the Energy, Global Change and Ecosystems Program (FP6-2005-Global-4).

NSERC CRSNG

Canada Research Chair in Water Quality Modeling