Virtual sensors and Process Control

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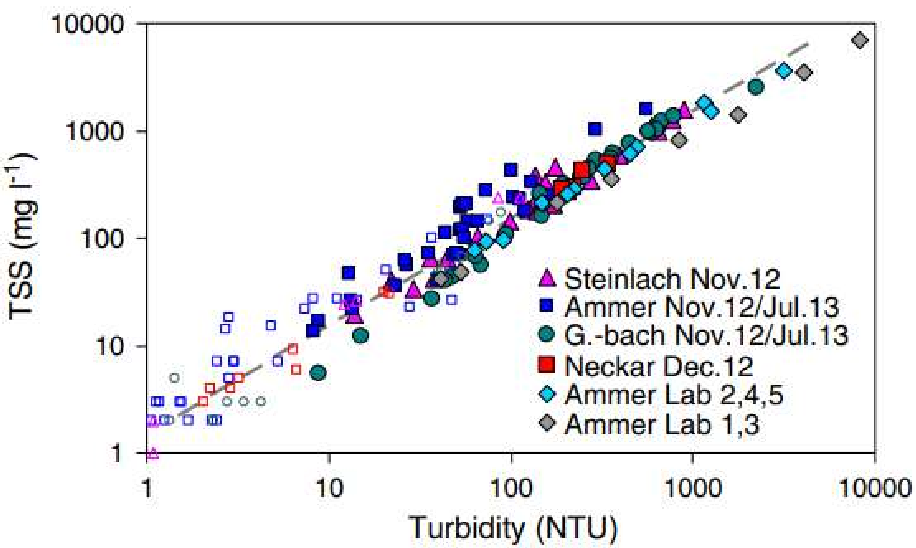
Acknowledgement: selected slides from Dr Abhilash Nair

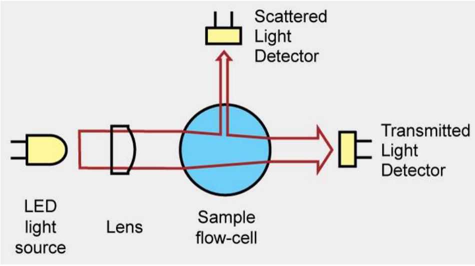
BigData in process surveillance

- Virtual sensors
- Validation of measurements
- Estimation of missing parameters
- Process analytics

Virtual sensors (software sensors)

Typical example: measurement of SS via tuirbidity

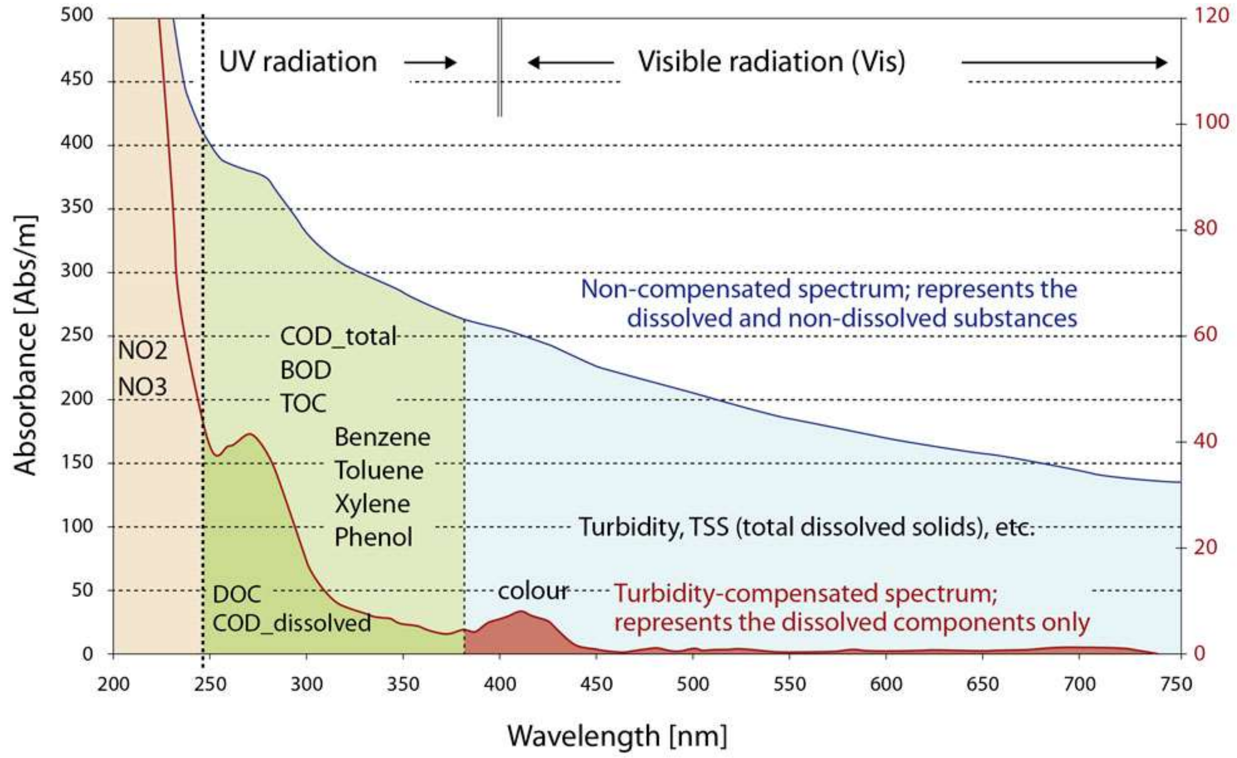




SS = f (Turbidity)

Scanning spectroscopy

TOC :: Color :: UV254 :: NTU :: FNU :: COD:: Alarm ..



«Anything is possible»

	Drinking Water		Environmental		Municipal Waste Water			Industrial			
	Drinking Water	Ground Water	River/Surface Water	Sea Water	Effluent Municipal	Aeration	Influent Municipal	Dairy	Paper Influent	Paper Effluent	Brewery
	D	G	R	O	E	A	I	M	P	Q	B
TSS			■		■		■	■	■	■	■
TS						■					
Turbidity	■	■	■	■	■						
Color app / true	■	■	■	■	■		■				
TOC	■	■	■	■	■		■				
DOC	■	■	■	■	■		■				
BOD			■		■		■				
COD / CODf			■		■	■	■	■	■	■	■
NO3-N / NO3	■	■	■	■	■	■	■	■	■	■	■
Chloramine	■										
HS-		■	■				■				
O3	■				■						
CLD	■										
Chl-a			■								
BTX		■	■								
UV254 t / UV254 f	■	■	■	■	■	■	■	■	■	■	■
UV436 t / UV436 f	■	■	■	■	■	■	■	■	■	■	■
Single wavelength	■	■	■	■	■	■	■	■	■	■	■
Temperature	■	■	■	■	■	■	■	■	■	■	■
Fingerprint	■	■	■	■	■	■	■	■	■	■	■
Fingerprint comp	■	■	■	■	■	■	■	■	■	■	■

s::can

GO SYSTEMELEKTRONIK

WE MAKE LIQUIDS TRANSPARENT.

Multiple parameters with one physical probe

	max. Parameters	BOD	K+	COD	Chlorine Dioxide	BTX	Free / Total Chlorine	TOC	pH	DOC	O_2	UV254	NO_2-N	TSS	NH_4-N	Turbidity	Conductivity	Color	Peracetic Acid	Temperatur	Redox	O_3	Hydrogen Peroxide	H_2S	Chlorid	AOC	UV XXX	Fingerprint	Chloramin	Contaminant Alarm	CLD	NO_3-N	F-	Chl-a
spectro::lyser V3	19	■		■		■		■		■		■		■		■		■		■		■				■	■	■	■	■	■	■		■
spectro::lyser titanium pro	8	■		■		■		■		■		■				■		■		■		■					■	■		■		■		
spectro::lyser industrial ATEX	8	■		■		■		■		■		■		■		■		■		■		■		■		■	■	■	■	■	■	■		■
spectro::lyser UV	8			■		■		■				■	■	■		■				■		■		■			■	■		■		■		
i::scan	8			■				■		■		■		■		■		■		■														
carbo::lyser V3	3	■		■				■		■		■		■		■				■														
ozo::lyser V3	2													■		■				■		■												
nitro::lyser V3	2													■		■				■		■												
multi::lyser V3	4	■		■				■		■		■		■		■				■		■										■		
uv::lyser V3	5											■		■		■				■							■							
ammo::lyser pro	4		■						■						■					■												■		
ammo::lyser eco	4								■						■					■					■							■		
chlori::lyser	2						■													■														
chlodi::lyser	2				■															■														
hyper::lyser	2																			■			■											
peroxy::lyser	2																		■	■														
condu::lyser	2																■			■														
redo::lyser	2																			■	■													
pH::lyser	2								■											■														
fluor::lyser	2								■											■													■	
soli::lyser	1													■																				
oxi::lyser	2										■									■														

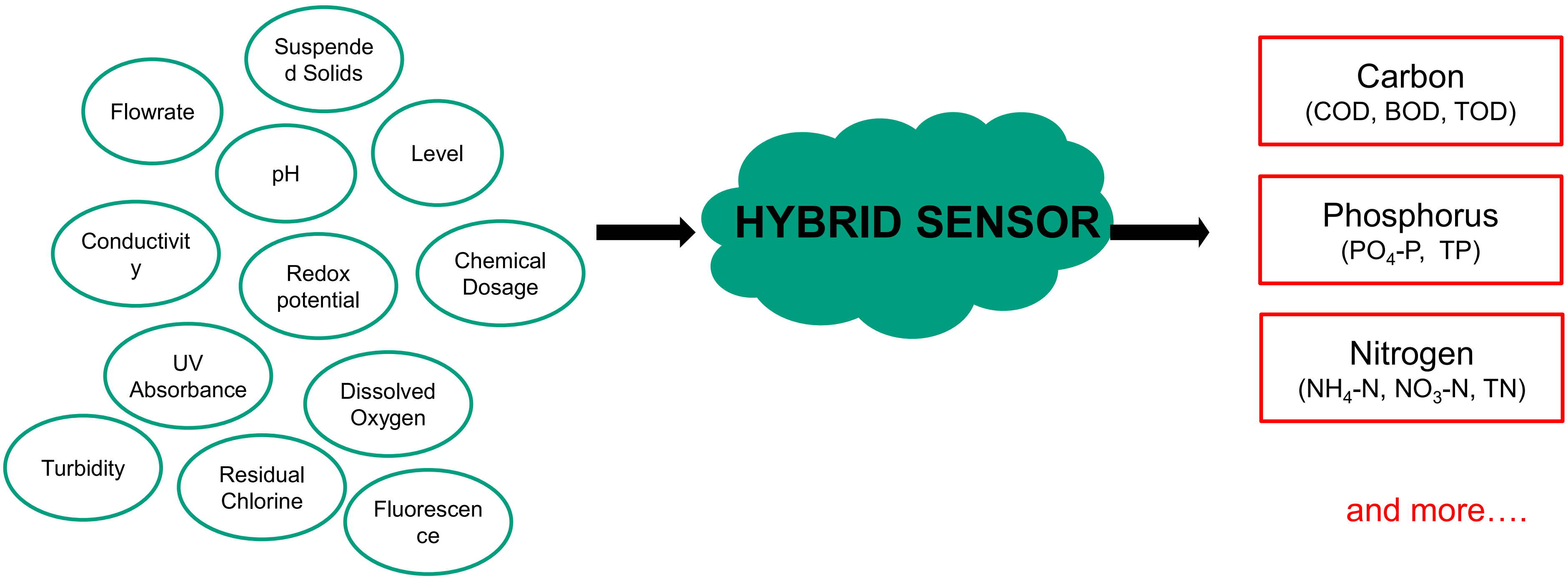
Hybrid sensors

Secondary variables (physical probes)

- Easy-to-measure
- Reliable
- Low capital costs
- Low maintenance

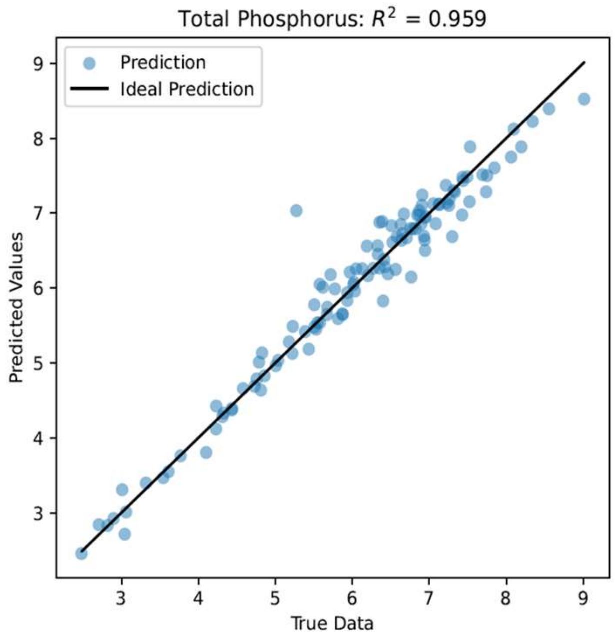
Primary variables (Hybrid sensors)

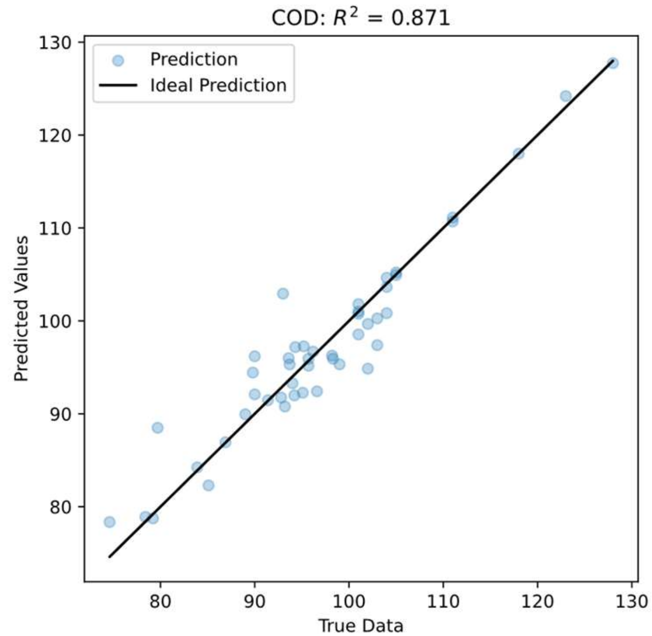
- Hard-to-measure
- Expensive
- High maintenance costs
- Time delayed-response



and more….

Virtual /Hybrid sensors





EDITOR'S CHOICE | AUGUST 12 2019

Implementing an Extended Kalman Filter for estimating nutrient composition in a sequential batch MBBR pilot plant

Abhilash M. Nair; Abaynesh Fanta; Finn Aakre Haugen; Harsha Ratnaweera

Check for updates

Water Sci Technol (2019) 80 (2): 317–328.
https://doi.org/10.2166/wst.2019.272 **Article history**

Open Access | Feature Paper | Article

Estimating Phosphorus and COD Concentrations Using a Hybrid Soft Sensor: A Case Study in a Norwegian Municipal Wastewater Treatment Plant

by Abhilash Nair [1,*], Aleksander Hykkerud [1] and Harsha Ratnaweera [1,2]

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[2] Faculty of Science and Technology, Norwegian University of Life Sciences, 1432 Ås, Norway
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Future of virtual and hybrid sensors

- Microbiological water quality
- Disinfection by products
- Emerging contaminants
- Water quality models for distribution pipes and sewers

- Combination of UV-VIS-Fluorescence spectra…

Is it possible to predict the treated water quality?

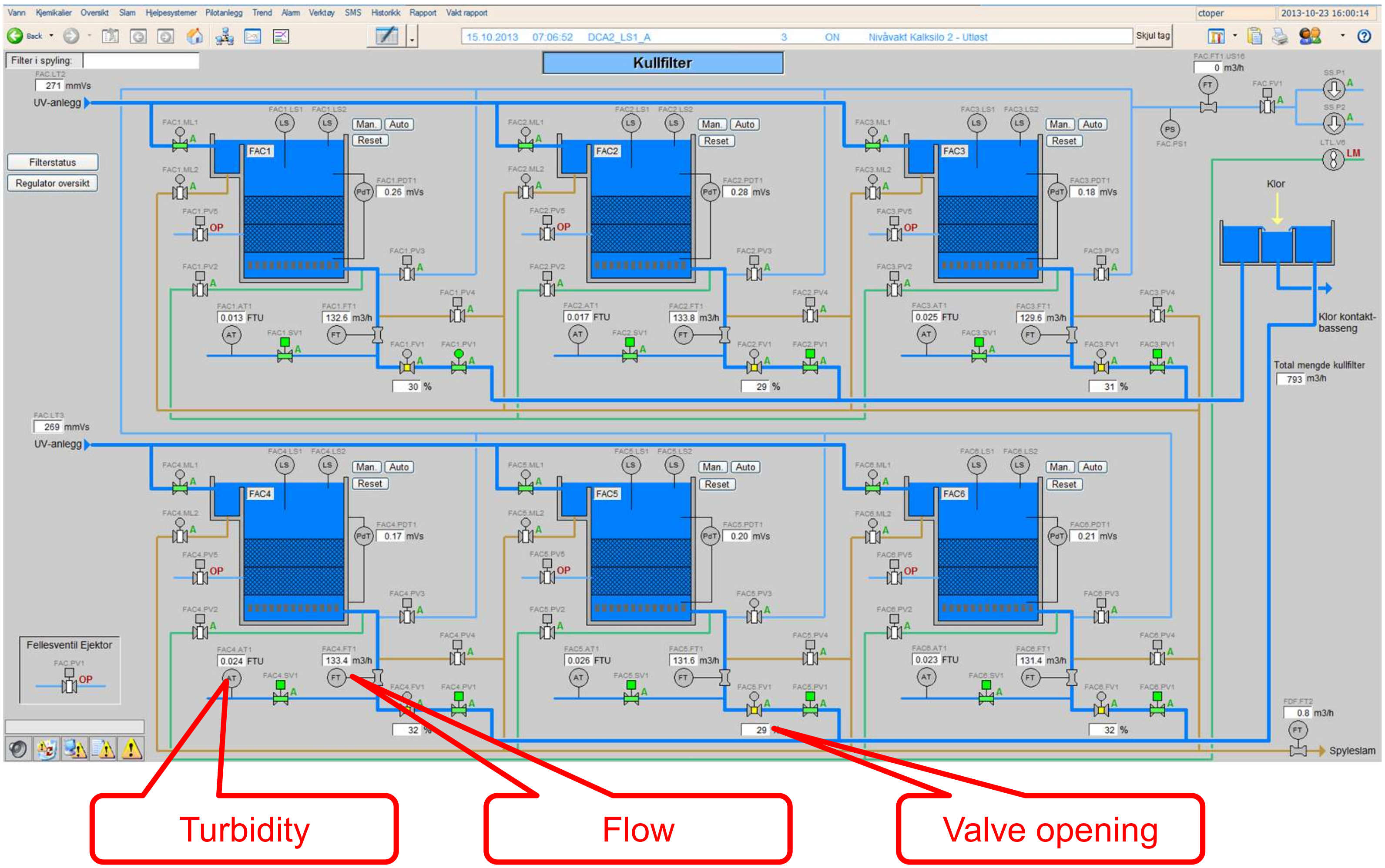
- Yes, if we have good and well-calibrated models
  - But not all the processes and parameters can be predicted

- Machine learning / AI is a new possibility

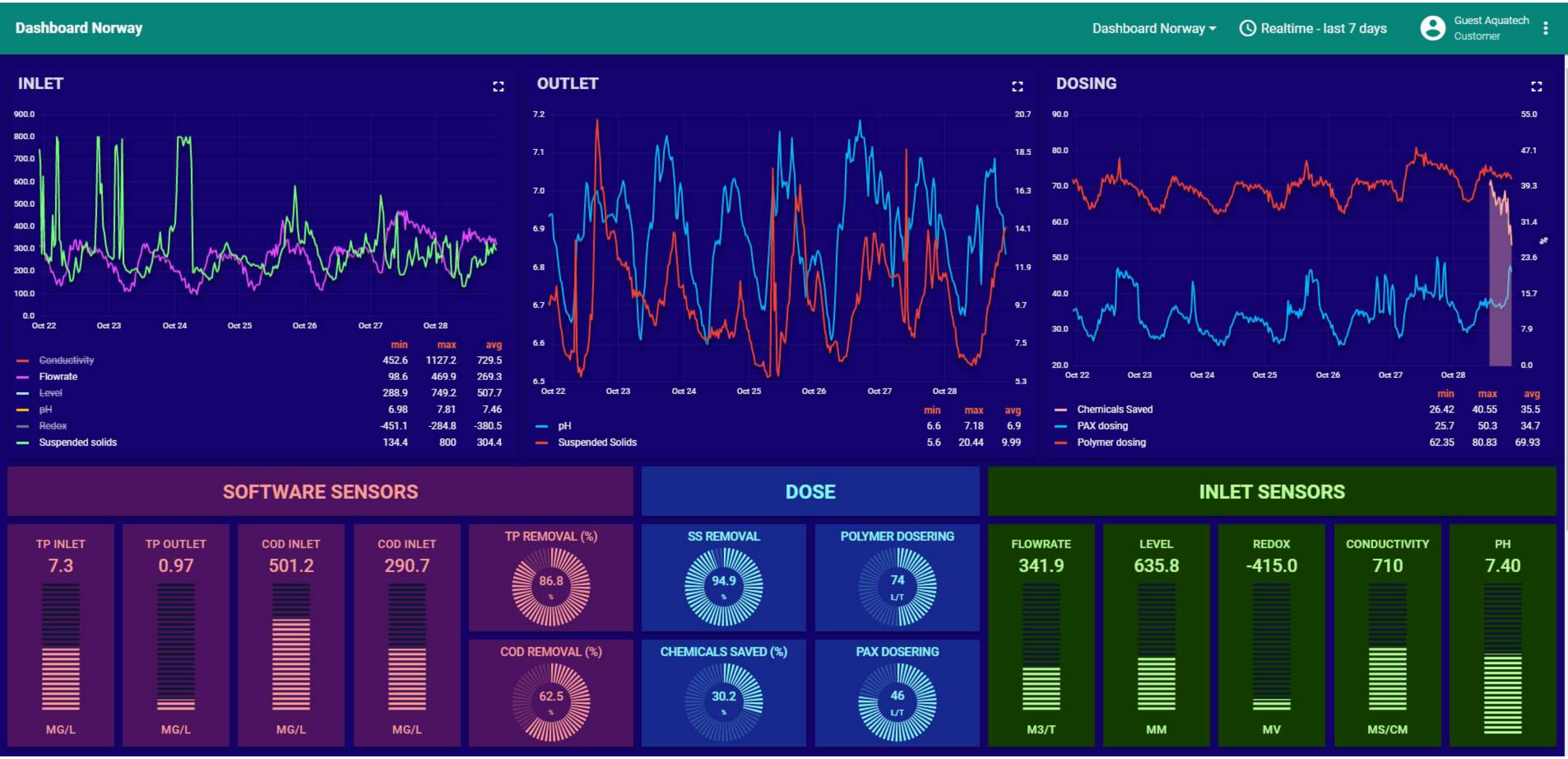
Validation of measurements

- Online sensors: 24/7? 365d?: Calibration, cleaning, drifting adjustment
- Hardware error limits are often not adequate (0<pH<14)
- Moving error limits, based on models or historical data
- If not validates, provide a best possible estimate
- Forecasting of effluent quality

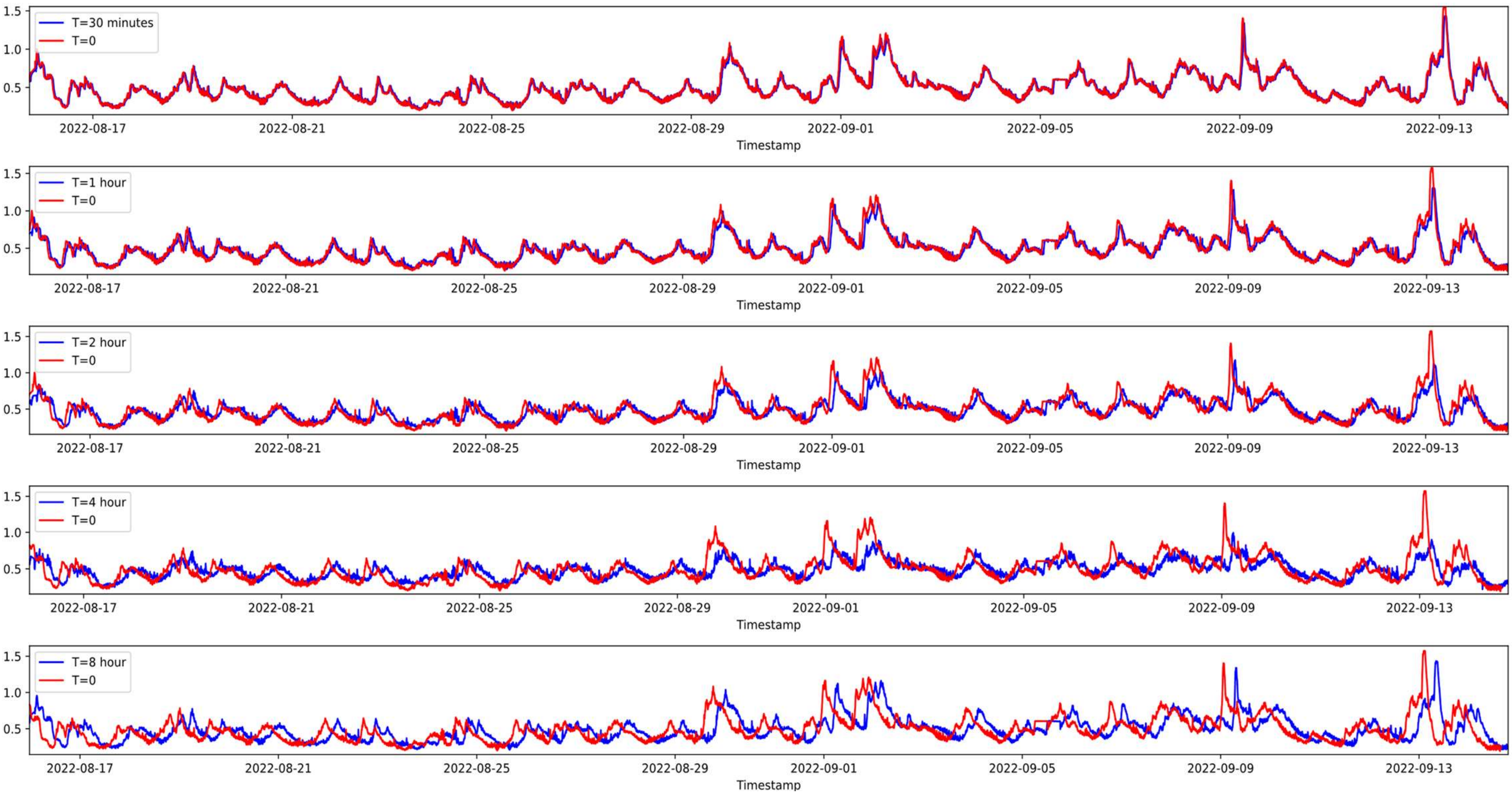
Example: use of online instruments at a drinking water plant: Activated Carbon filter



Process analytics



Forecast results (total phosphorus)



Outline

- What is process control
- How does it work: in everyday life, examples of control elements, structures
- Why do we need process control in W&WWT?
- Examples

What is Process Control ?

Methods and techniques used in systems to automatically correct their own behavior so that specifications for this behavior are satisfied.

ISA-International Society for Automation

Techniques implemented in process to achieve stable performance.

Beigler L.T. Chemical Process Design 1st Edition

Automating processes for consistency, economy and safety which could not be achieved purely by human manual control

Business Dictionary

System used to keep key process-operating parameters within narrow bounds of the reference value or setpoint.

Werther, Samuel P. Process Control: Problems, Techniques, and Applications

Elements of Process Control

- Online Sensors
- Controller
- Actuator
- Control Algorithm

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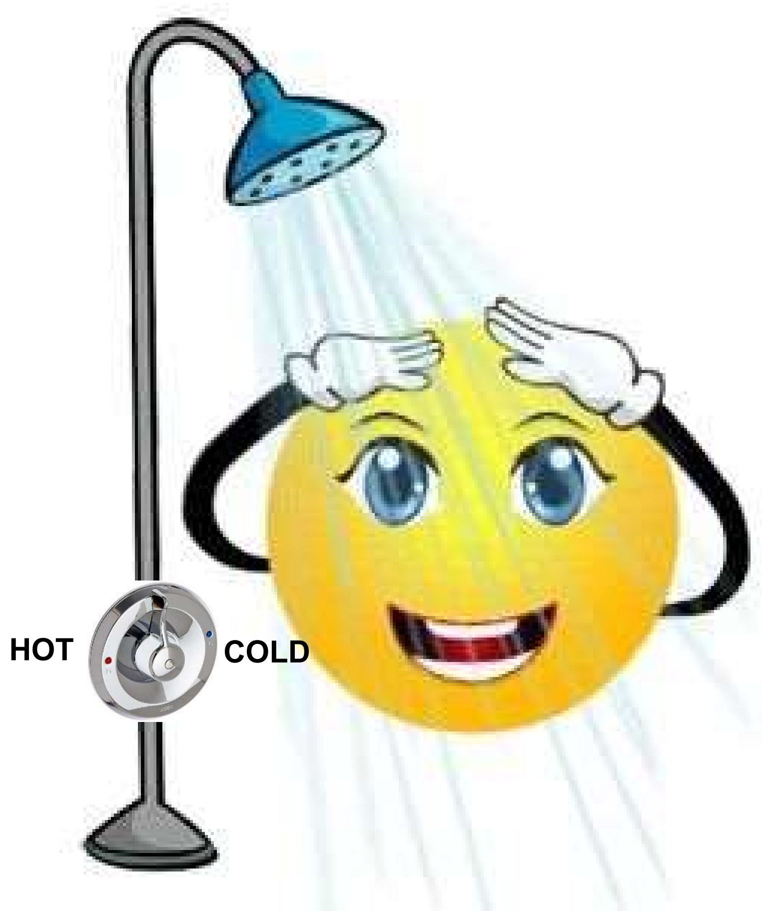
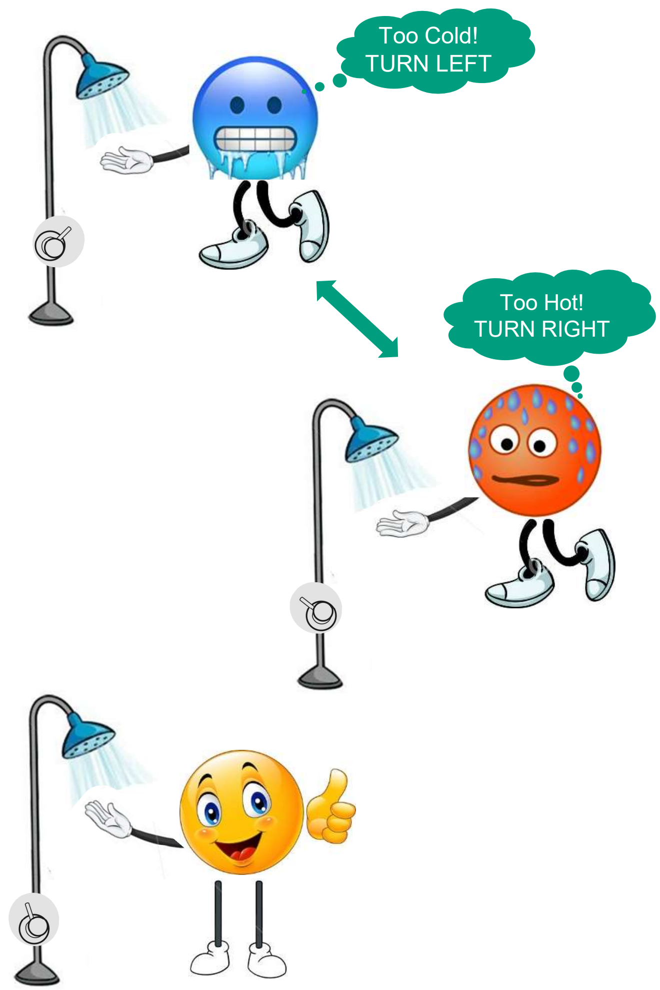
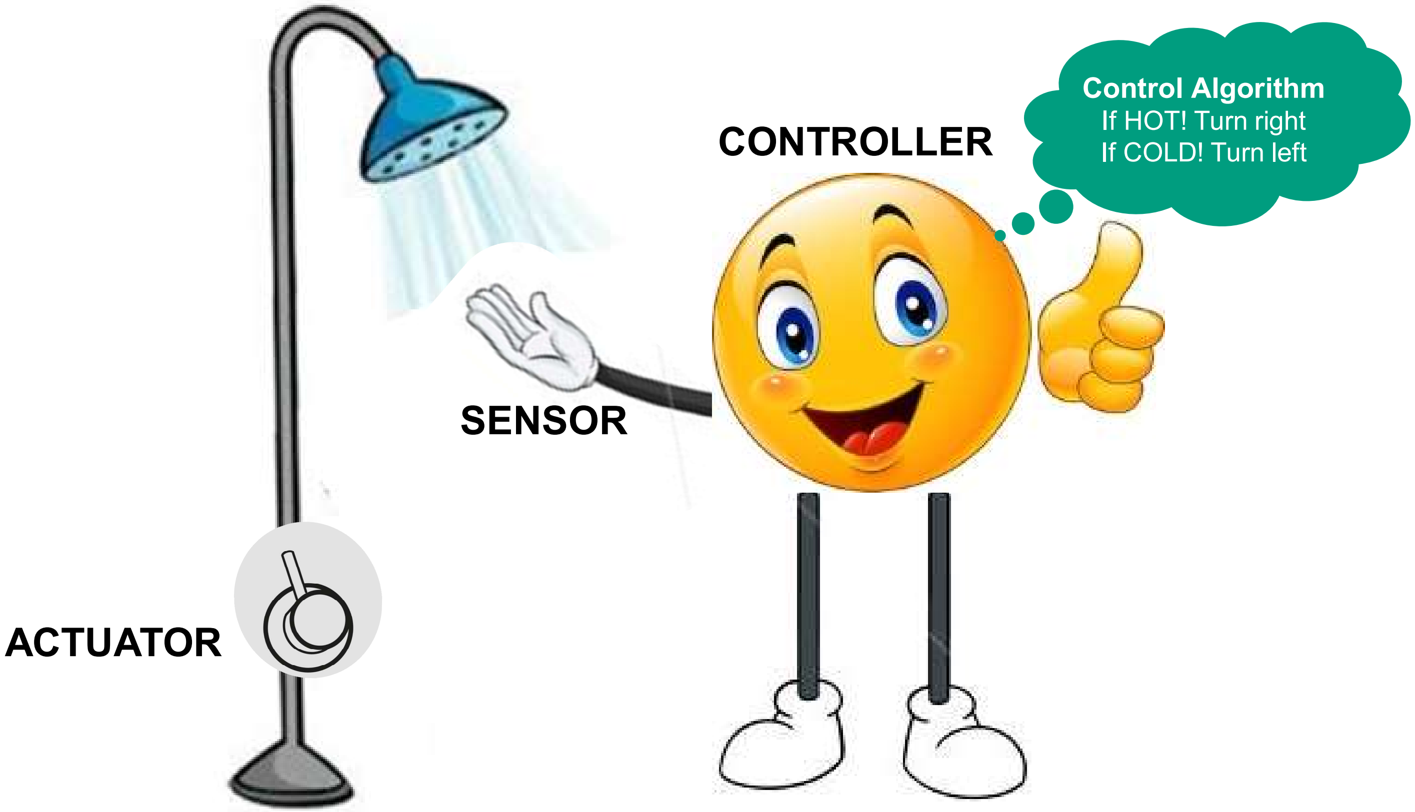
Process Control in Everyday Life!

Getting the right temperature

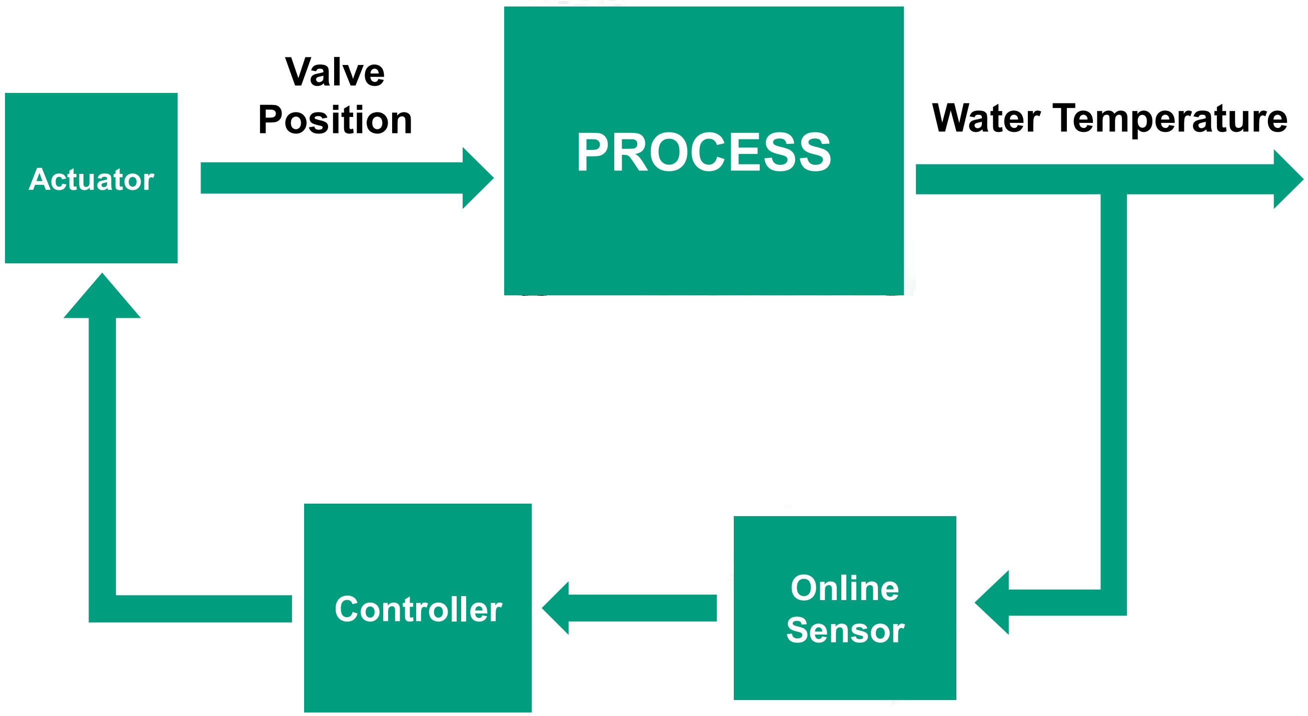




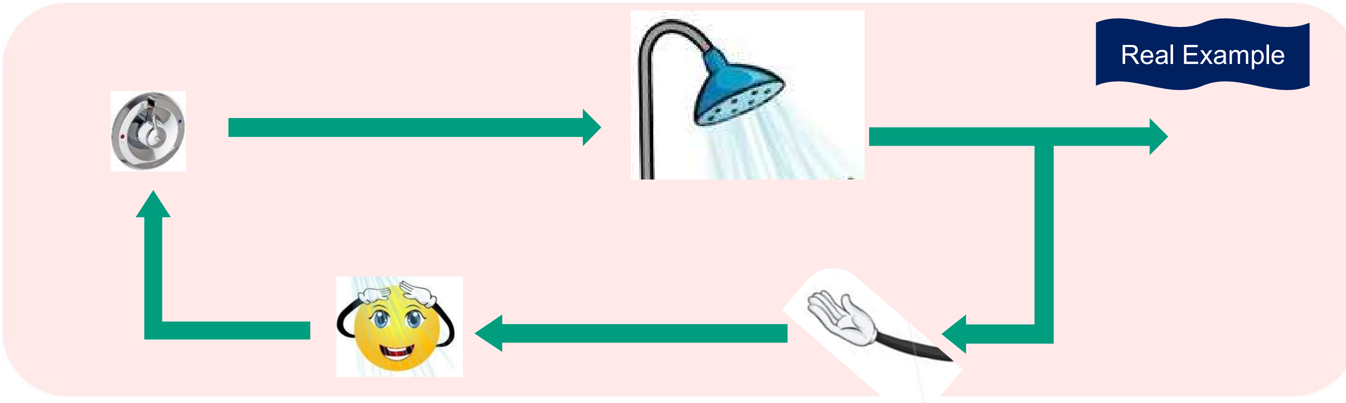
Elements of Process Control

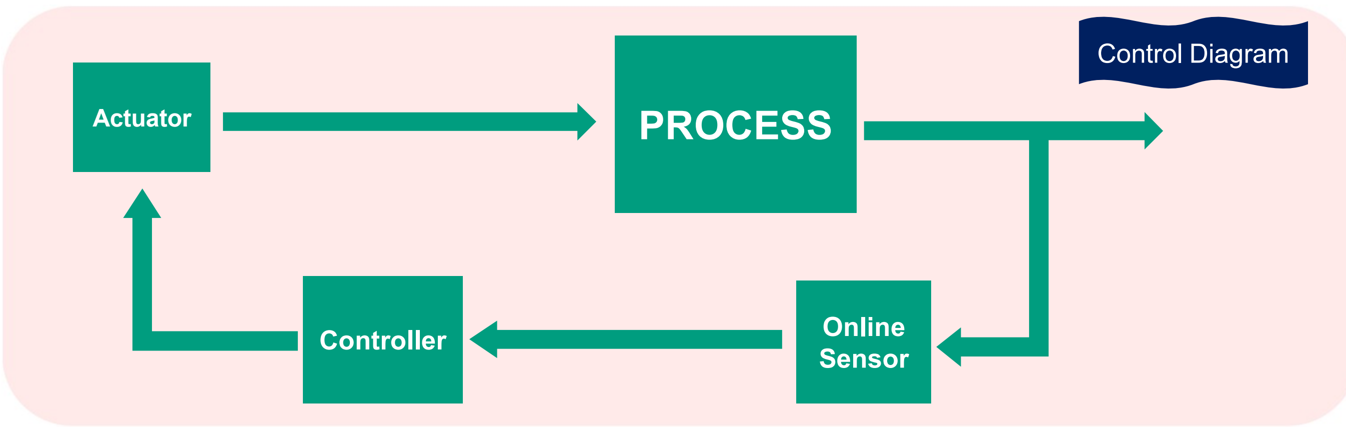


Control Diagram



Control Diagram





Examples of Control Elements

Online Sensors

DO sensors

S:CAN Spectrolyser

Nitrate sensor

Phosphate Analyser

Duncan's Arm

Ammonium Sensor

PLC – Programmable Logic Controllers

Microcontroller
(Arduino)

Single-board computers
(Raspberry Pi)

Controllers

Relays

PAC – Programmable Automation Computer

Human/Duncan's
Brain

Control Valve/
Positioner

Variable Frequency Drive

Actuators

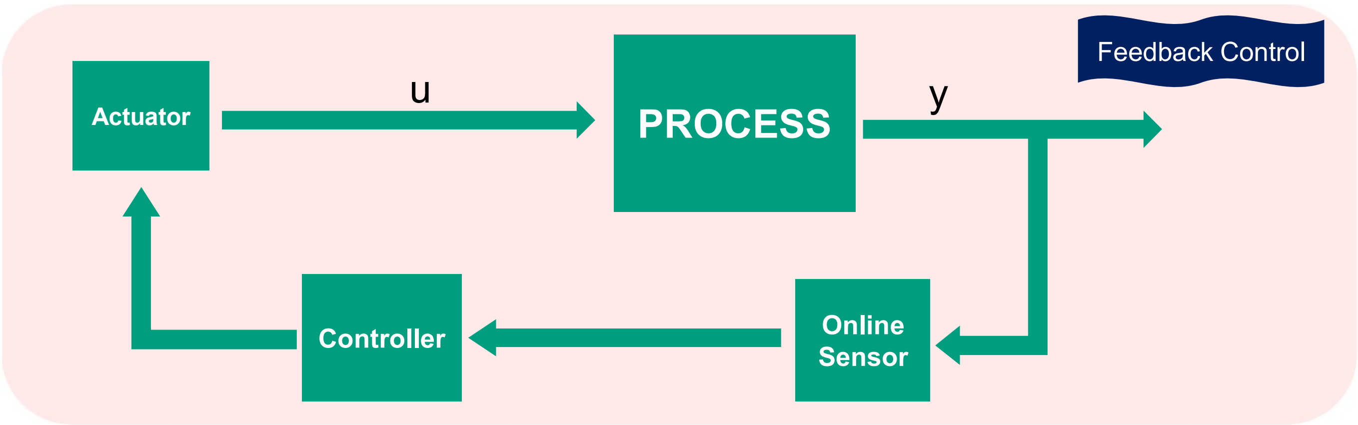
Aeration Pump

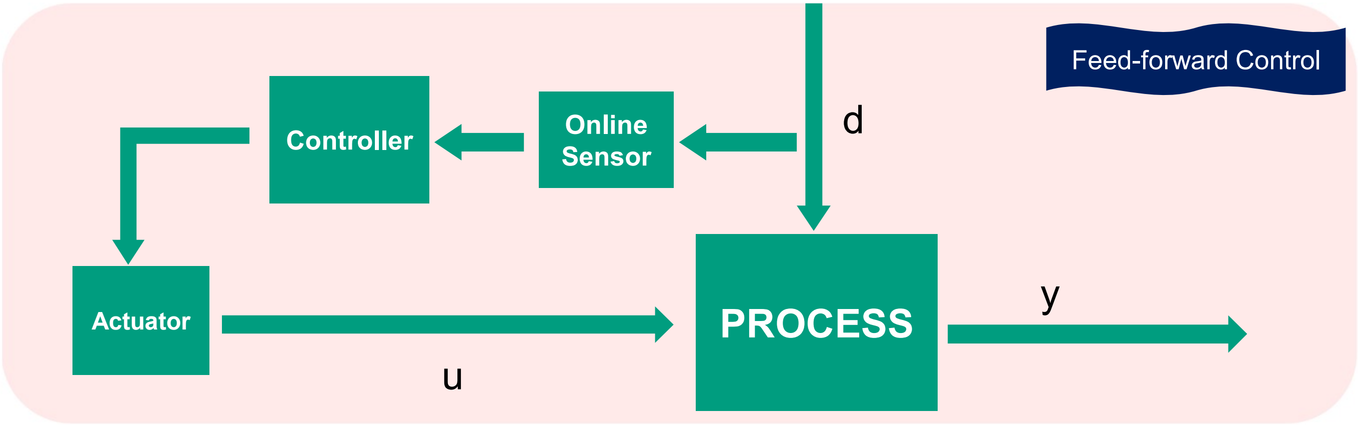
Dosing Pump

Shower Knob

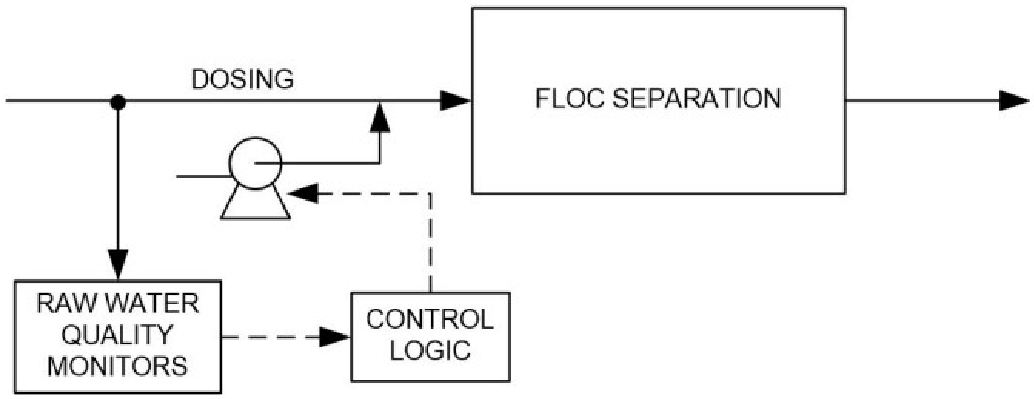
Control Structure

Control Structure

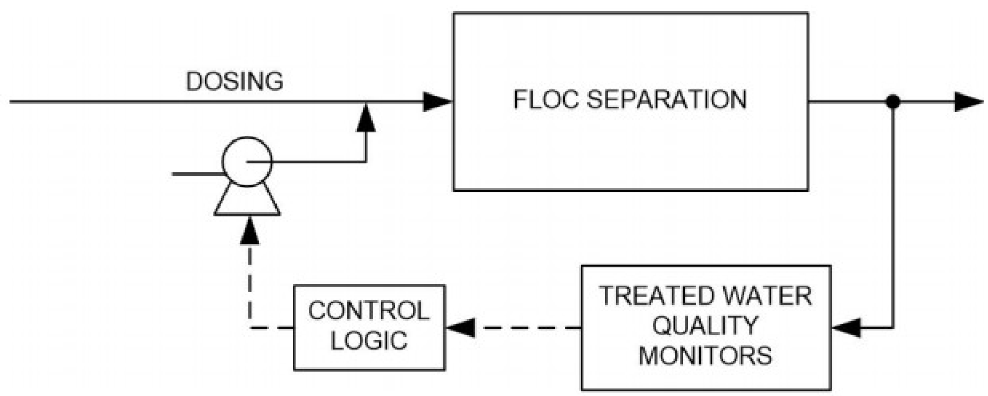




Examples



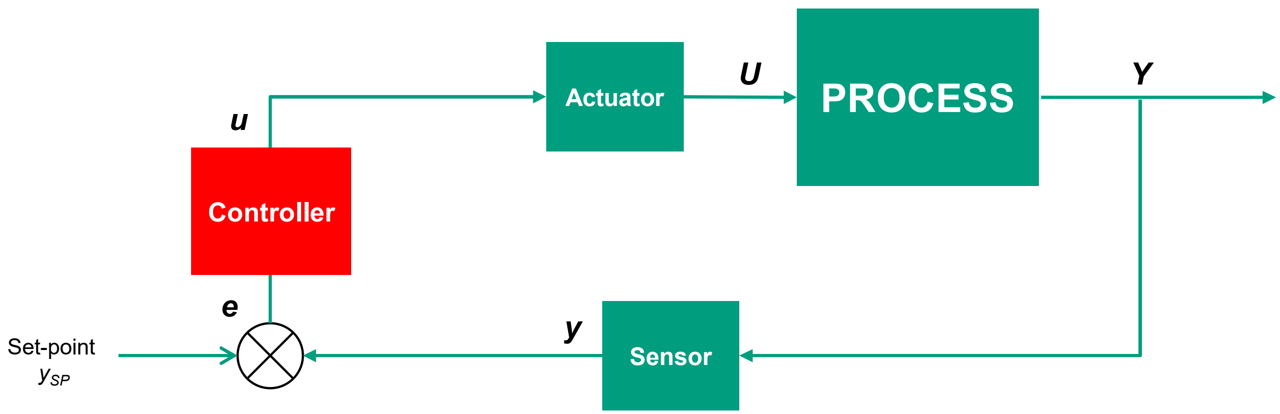
Feed-forward Control

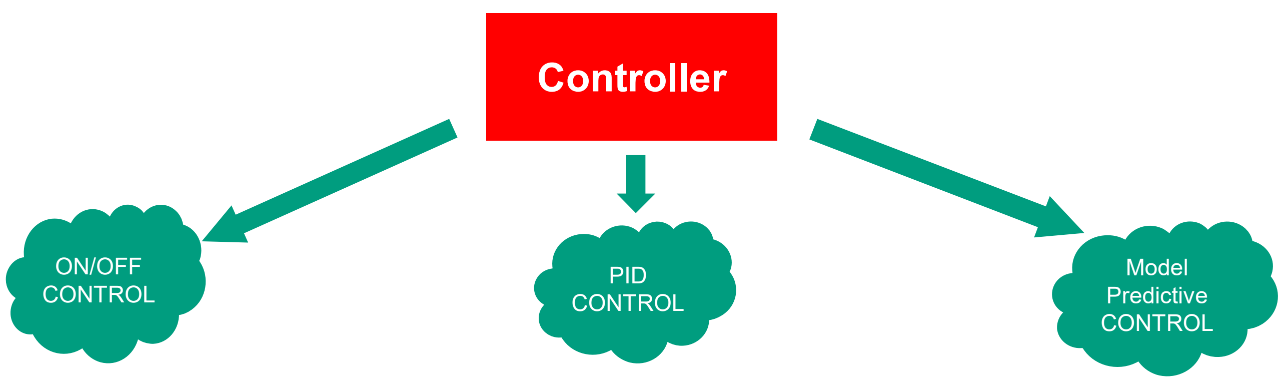


Feedback Control

* Ratnaweera & H. Fettig J. (2015) State of the Art of Online Monitoring and Control of the Coagulation Process, *Water,* **7**(11), 6574-6597.

Control Algorithm



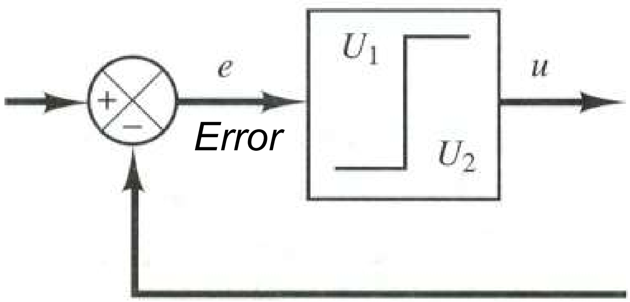


$$u(t) = \begin{cases} u_0 - U_{\min} & if\ e(t) > 0 \\ u_0 + U_{max} & if\ e(t) < 0 \end{cases}$$

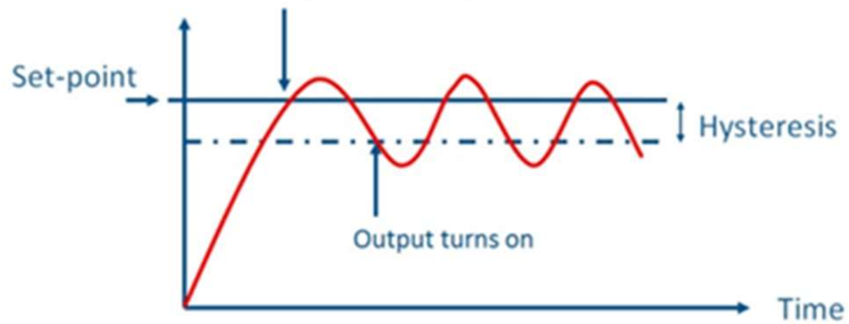
$$u(t) = u_0 + K_p e(t) + \frac{1}{T_I}\int e(t)dt + T_s\frac{de(t)}{dt}$$

$$u(t) = \min_{p,u} \sum_{i=0}^{n_p} w_x\, e_i^2 + w_u \Delta u_i^2$$

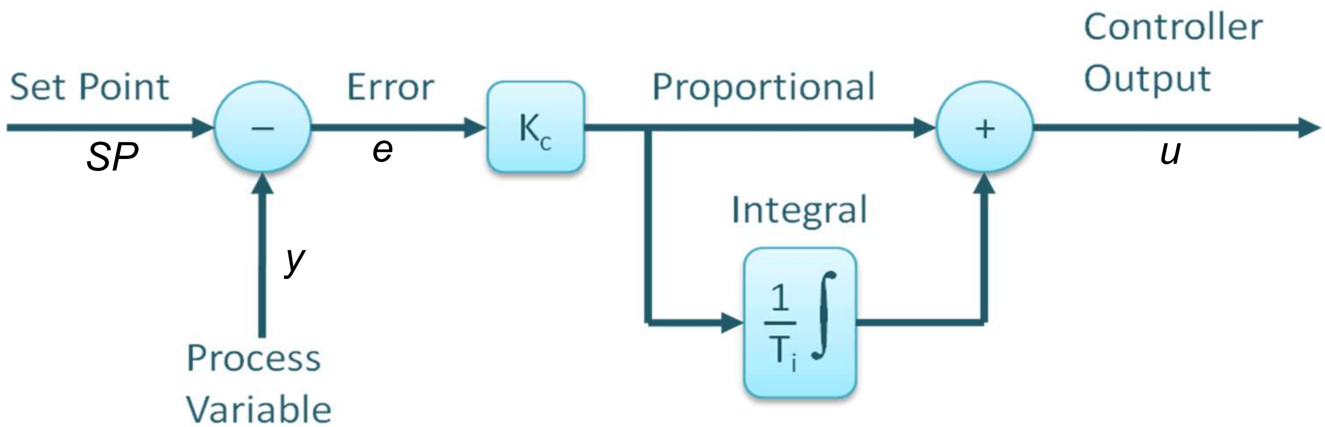
ON-OFF Control



$$u(t) = \begin{cases} U_1 & if\ e(t) > 0 \\ U_2 & if\ e(t) < 0 \end{cases}$$



PI Control



MATHEMATICAL EXPRESSION

$$u(t) = u_0 + K_C\, e(t) + \frac{1}{T_I}\int e(t)dt$$

$K_C \quad = \quad Proportional\ Constant$

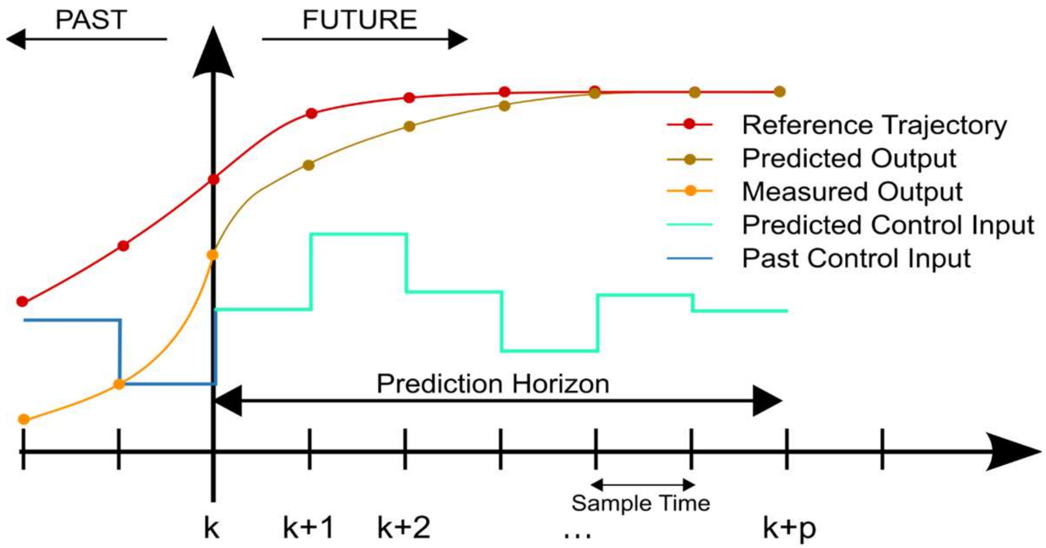
$T_I \quad = \quad Integral - Time\ Constant$

TUNING METHODS

1. *Ziegler– Nichols method*
2. *Cohen–Coon*
3. *Relay (Åström–Hägglund) method*

* Finn Haugen, 'Basic DYNAMICS and CONTROL', *ISBN 978-82-91748-13-9*

MPC Control *Model Predictive Control*



MATHEMATICAL EXPRESSION

$$u(t) = \min_{u} \sum_{i=0}^{n_p} w_x\, e_i^2 + w_u \Delta u_i^2$$

$$e_i \;= SP_i - y_i$$

$$y_i \;= f(u_i)$$

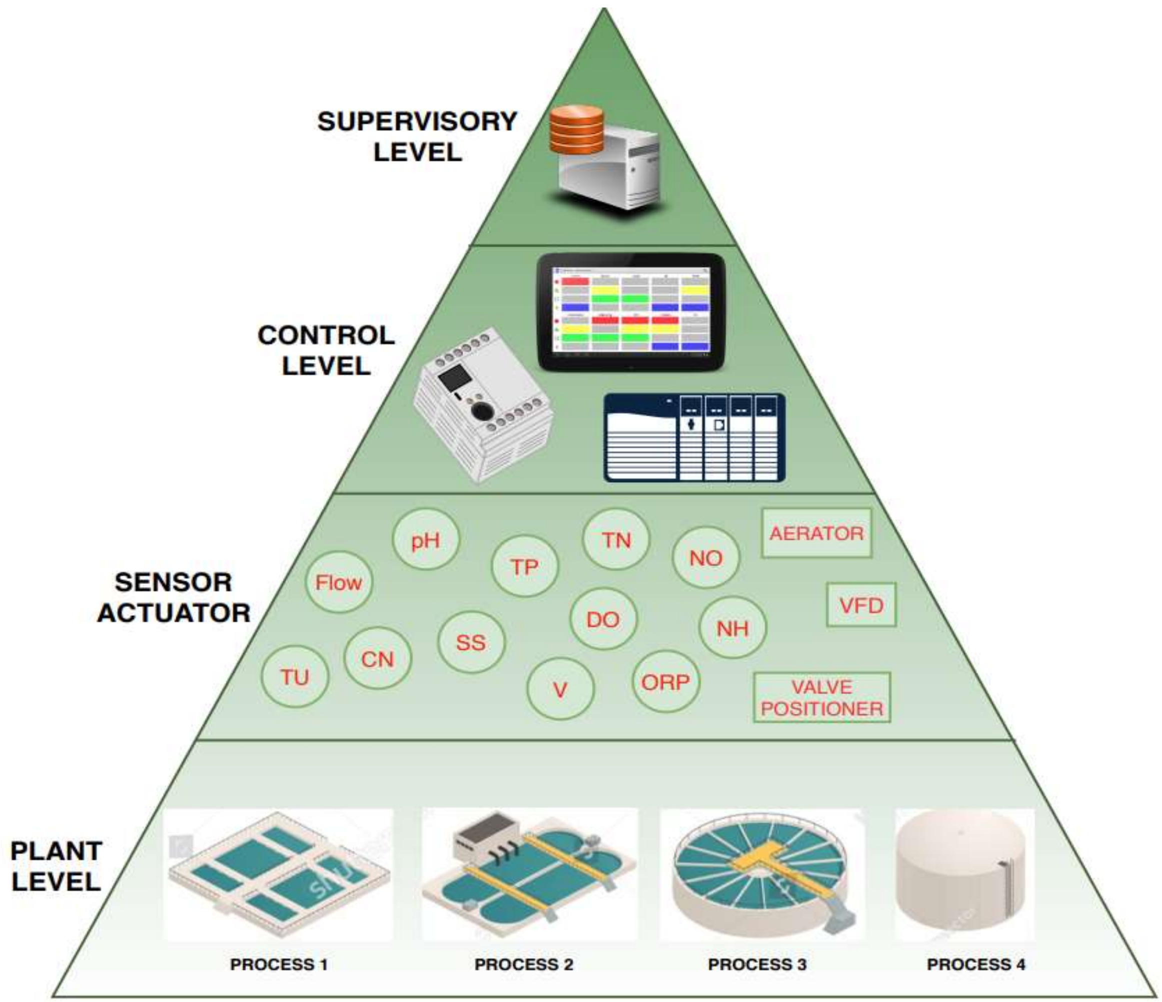
MPC TYPES

1. *Linear MPC*
2. *Non-Linear MPC*
3. *Adaptive MPC*

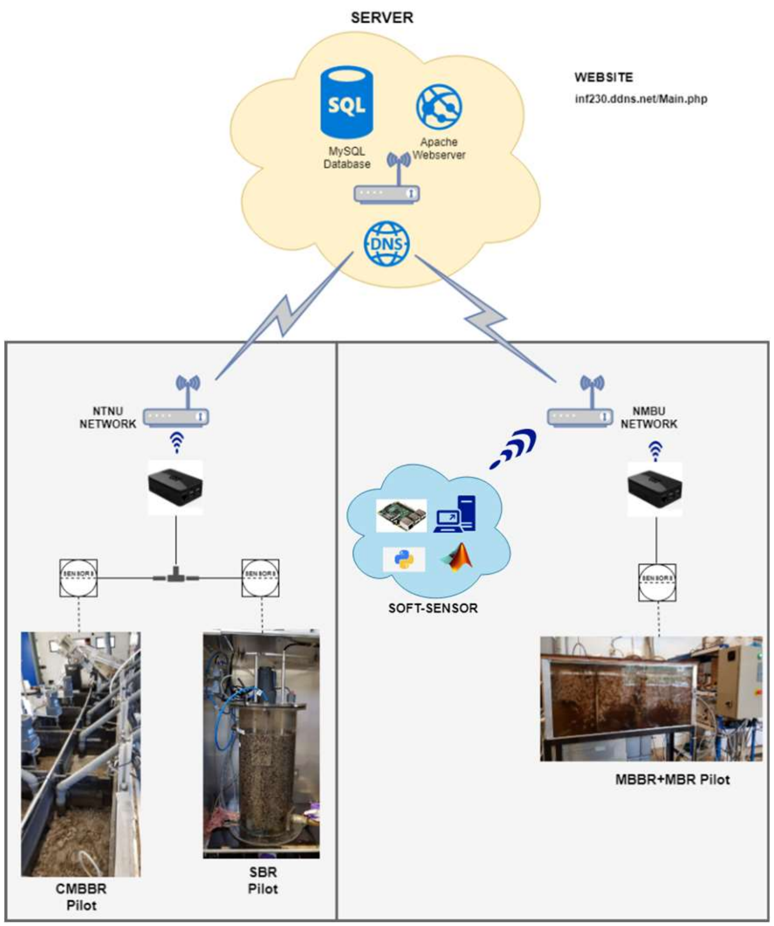
Terminologies

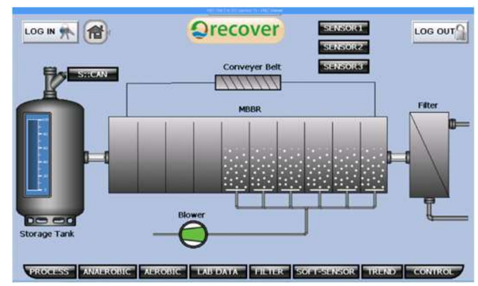
PLC	**-**	**PROGRAMMABLE LOGIC CONTROLLERS**
PAC	**-**	**PROGRAMMABLE AUTOMATION COMPUTER**
HMI	**-**	**HUMAN MACHINE INTERFACE**
RTU	**-**	**REMOTE TELEMETRY UNIT**
I/O	**-**	**INPUT OUTPUT MODULE**
DCS	**-**	**DISTRIBUTED CONTROL SYSTEM**
SCADA	**-**	**SUPERVISORY CONTROL AND DATA ACQUISITION**

Commercial SCADA architecture

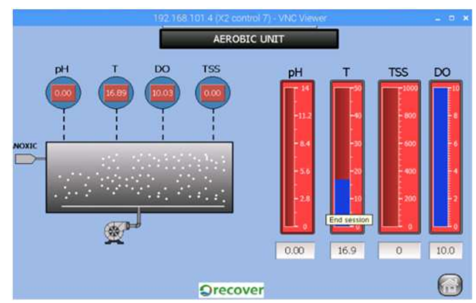


Network Architecture in SCADA

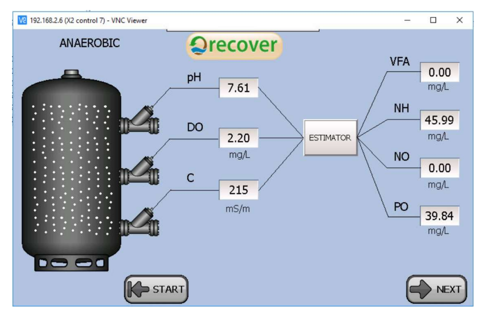




HMI Plant 1



HMI Plant 2



HMI Plant 3

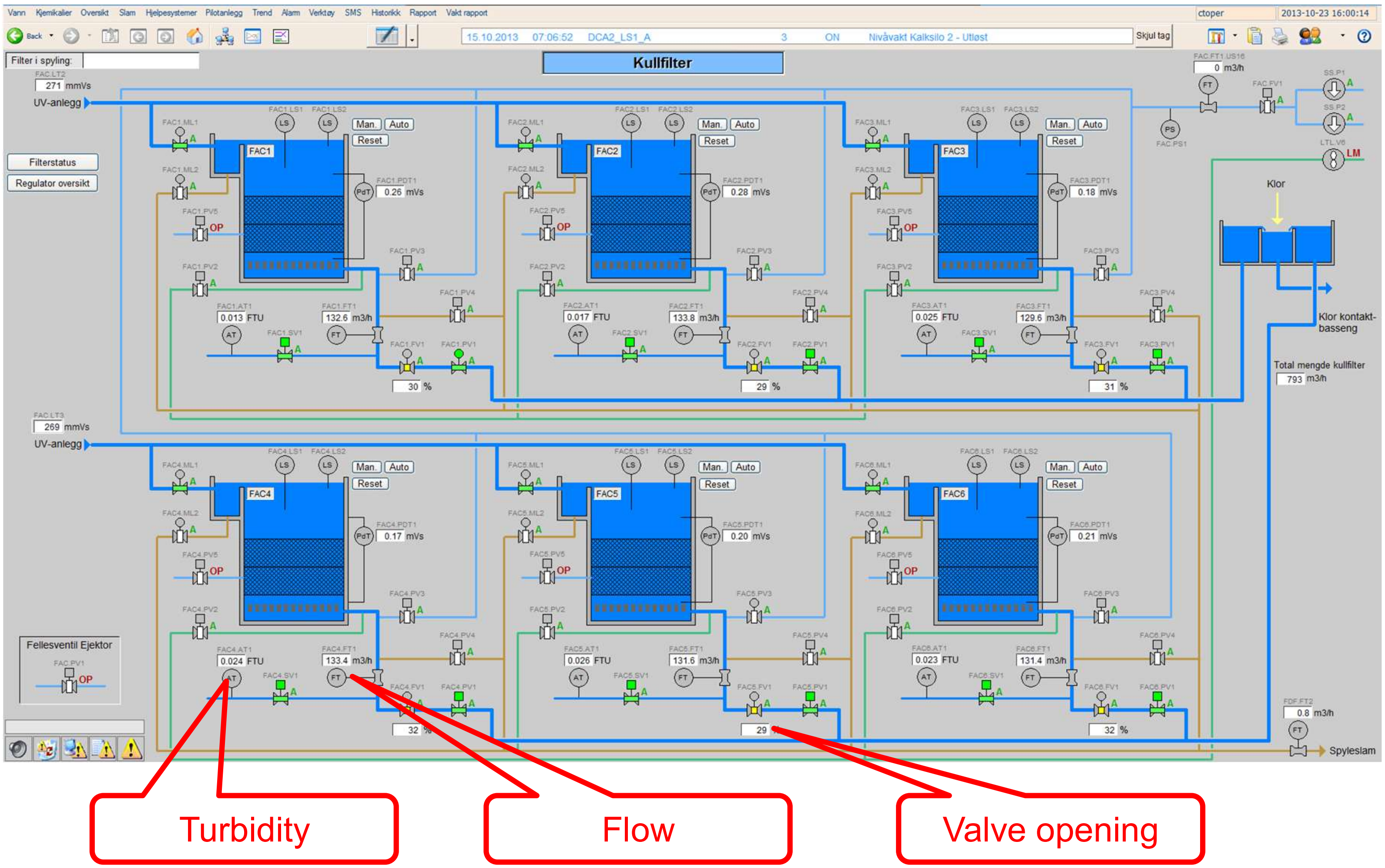
Control Room – Pre Digital Era

Coal Power Plant
Ref: http://power-controlsystem.com/

Control Room – Digital Era

Ref: TS Electro

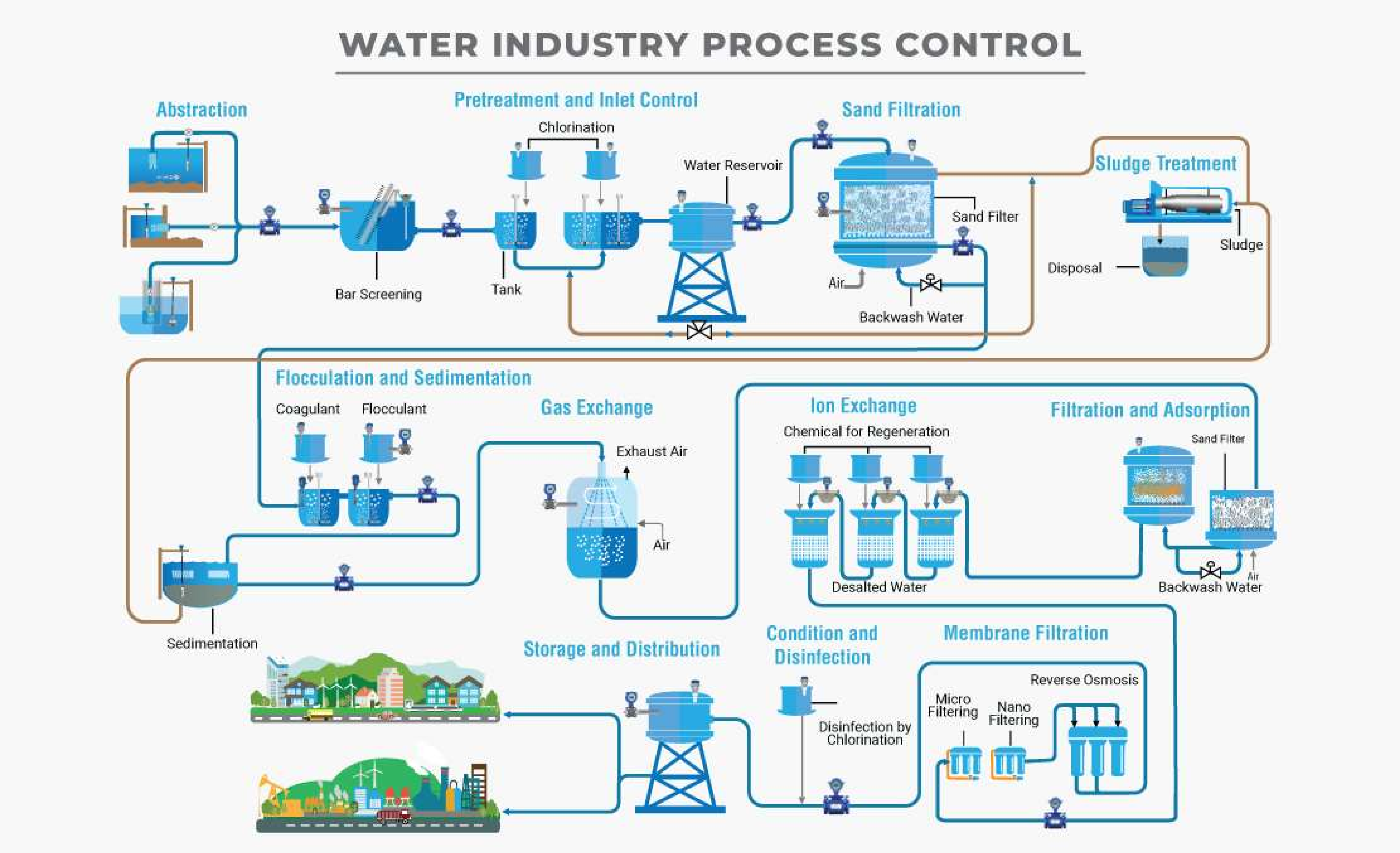
Example: use of online instruments at a drinking water plant: Activated Carbon filter



Outline

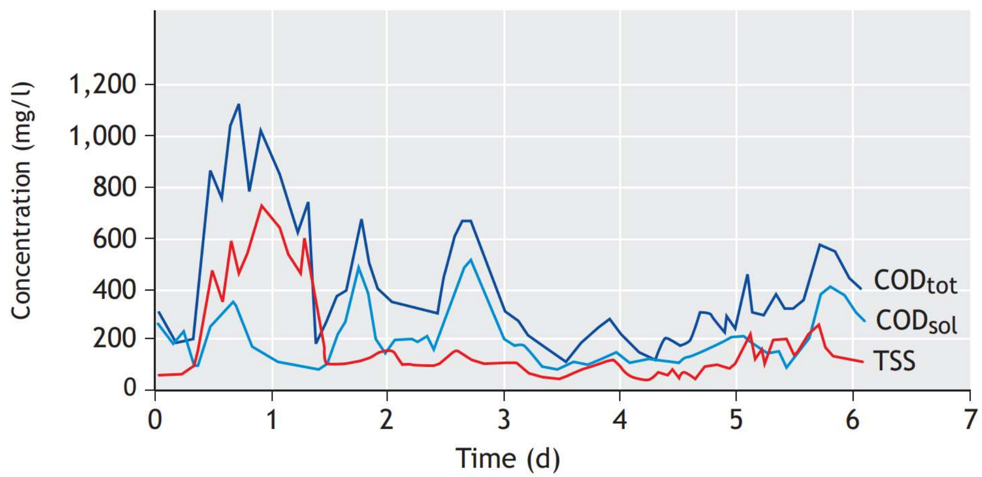
- What is process control
- How does it work: in everyday life, examples of control elements, structures
- Why do we need process control in W&WWT?
- Examples

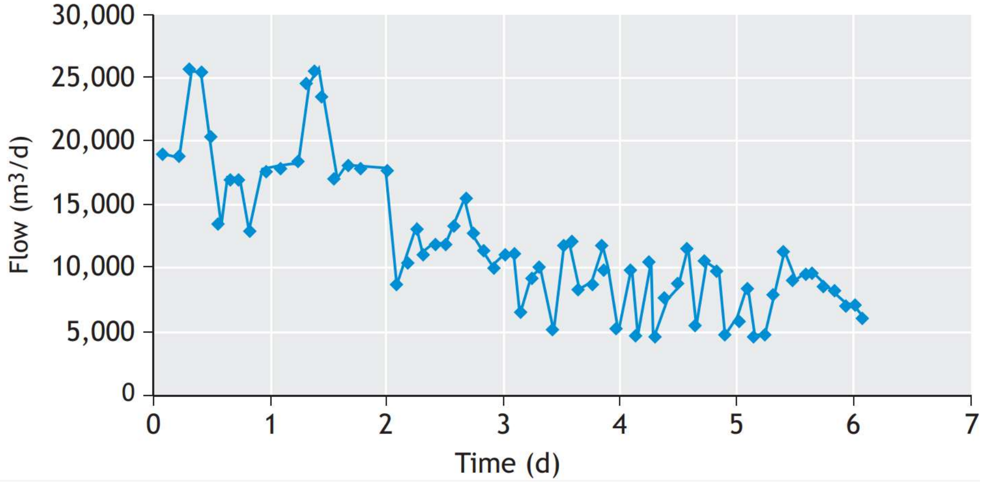
Why do we need Process Control in Treatment Plants?



WATER INDUSTRY PROCESS CONTROL
Abstraction
Pretreatment and Inlet Control
Chlorination
Water Reservoir
Bar Screening
Tank
Sand Filtration
Sand Filter
Air
Backwash Water
Sludge Treatment
Sludge
Disposal
Flocculation and Sedimentation
Coagulant
Flocculant
Sedimentation
Gas Exchange
Exhaust Air
Air
Ion Exchange
Chemical for Regeneration
Desalted Water
Filtration and Adsorption
Sand Filter
Air
Backwash Water
Storage and Distribution
Condition and Disinfection
Disinfection by Chlorination
Membrane Filtration
Reverse Osmosis
Micro Filtering
Nano Filtering

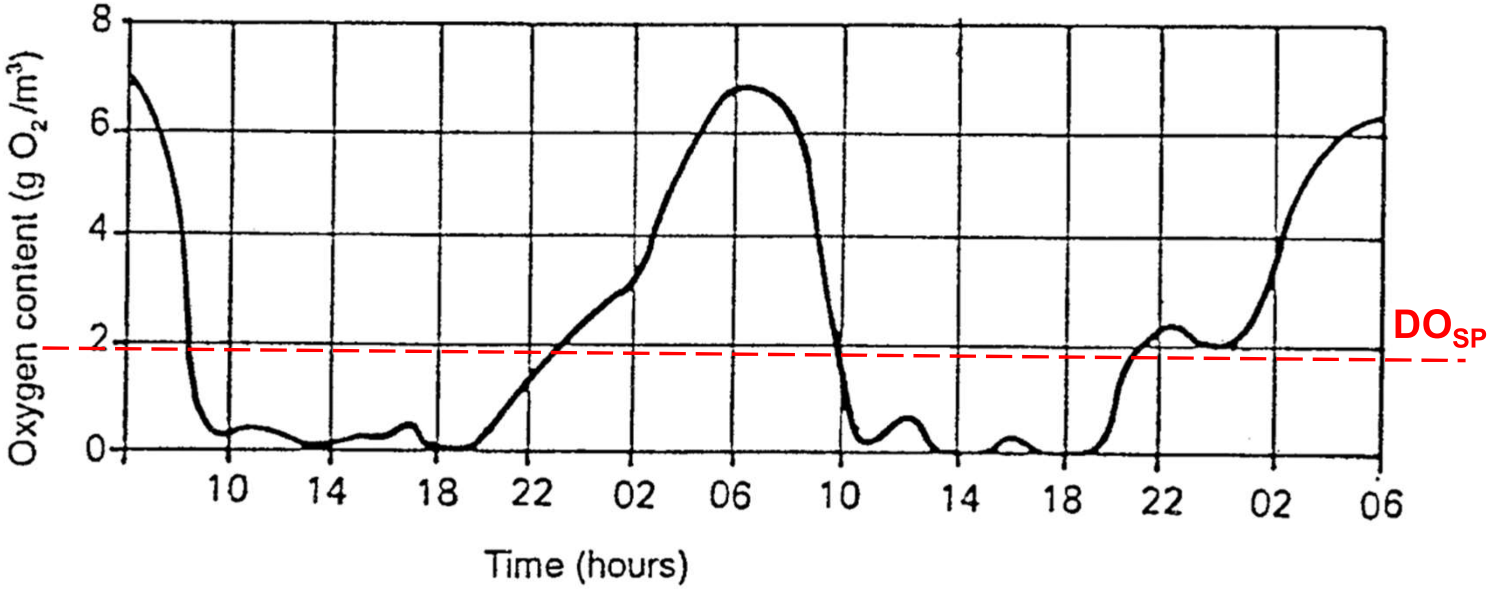
Influent Fluctuations





Henze *et al.* 2001

Aeration Basin without control



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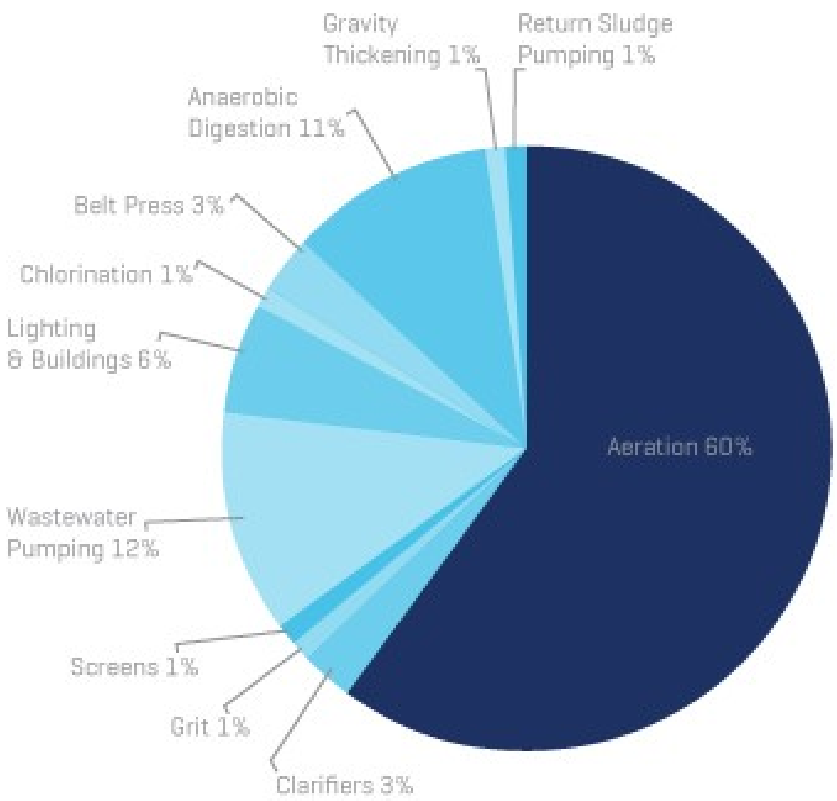
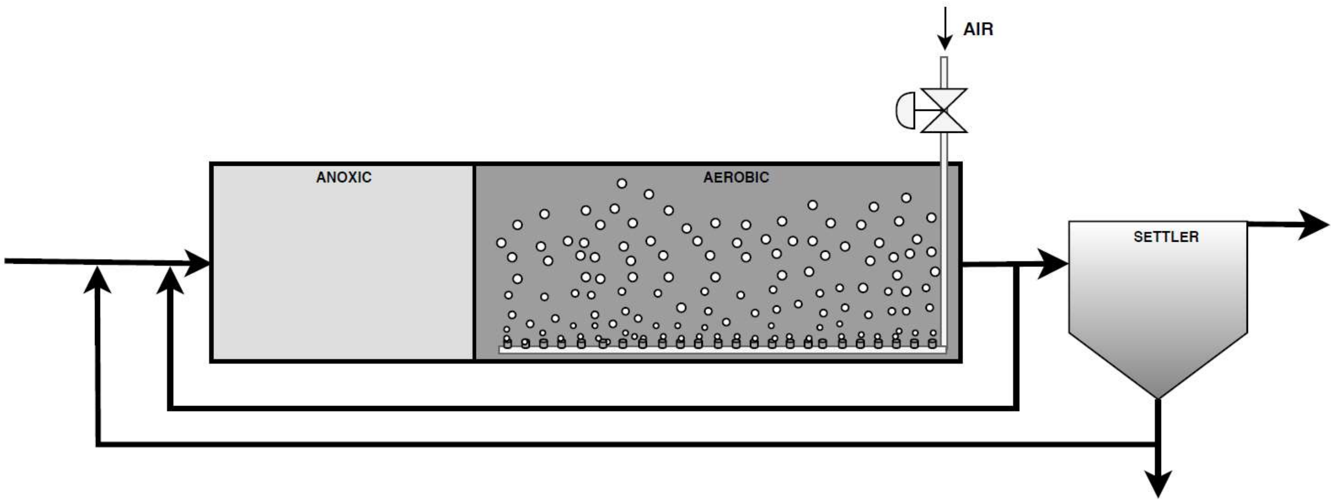
Case I: Dissolved Oxygen Control

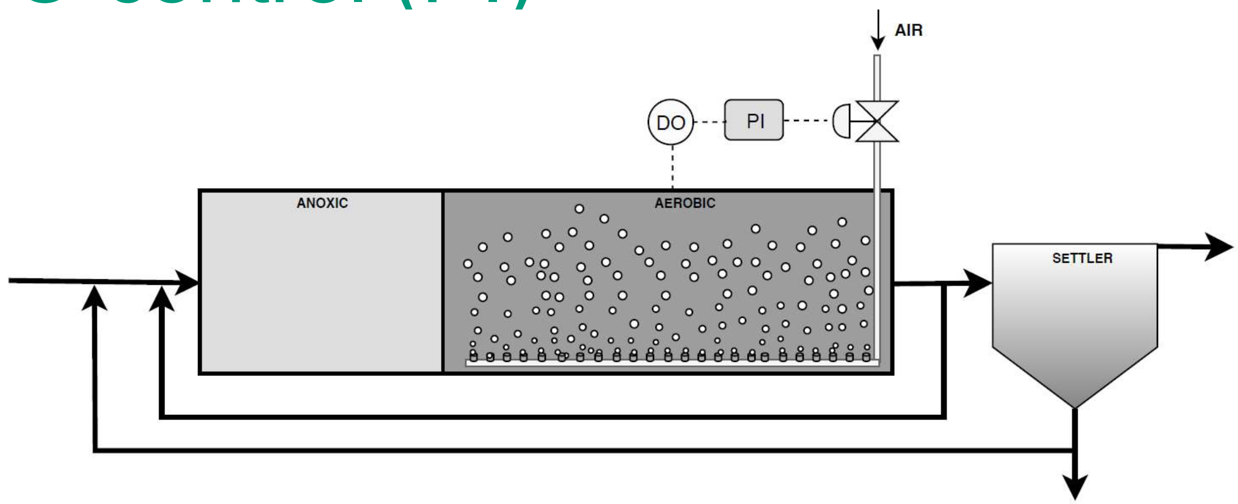
Energy usage in WWTP

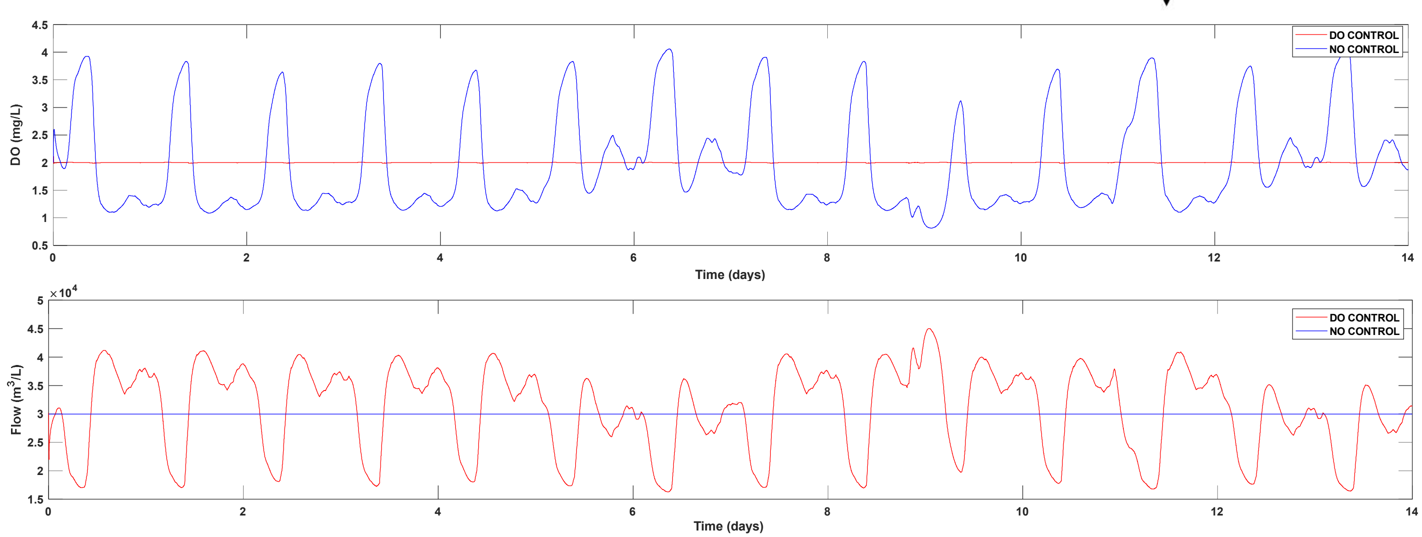


Biological WWTP

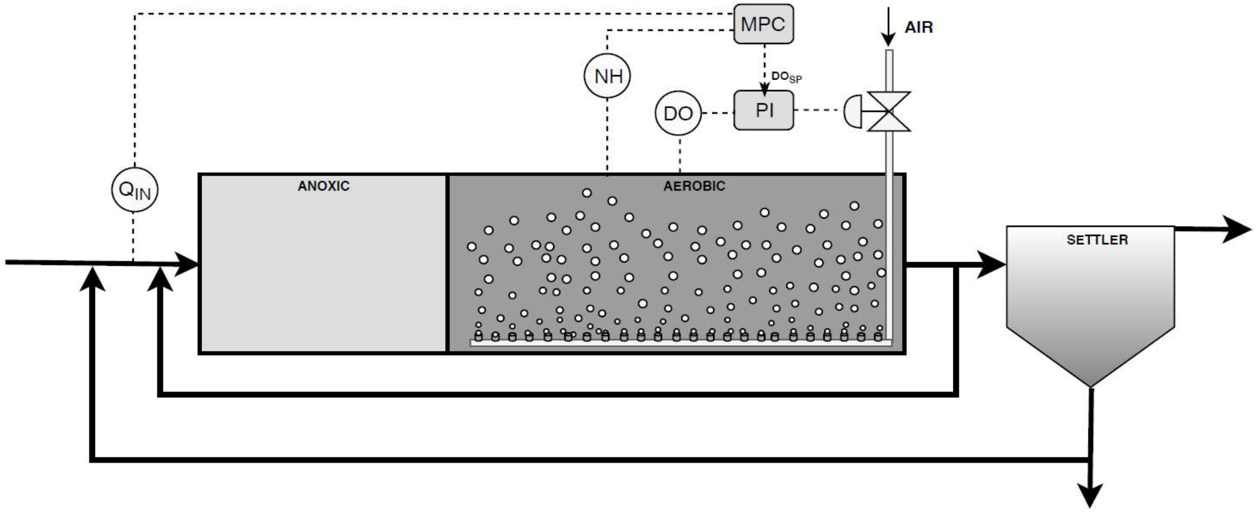


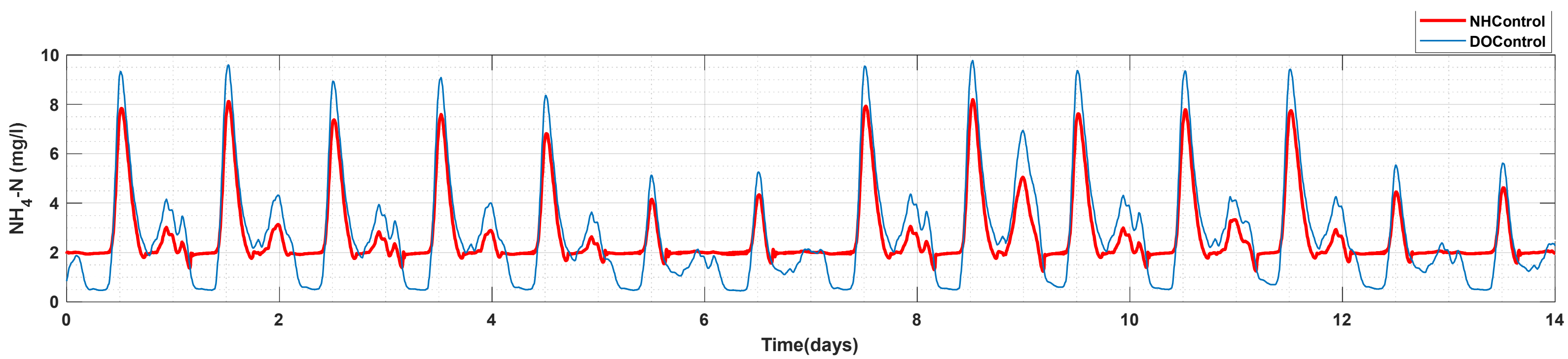
DO control (PI)





Ammonia control (MPC)



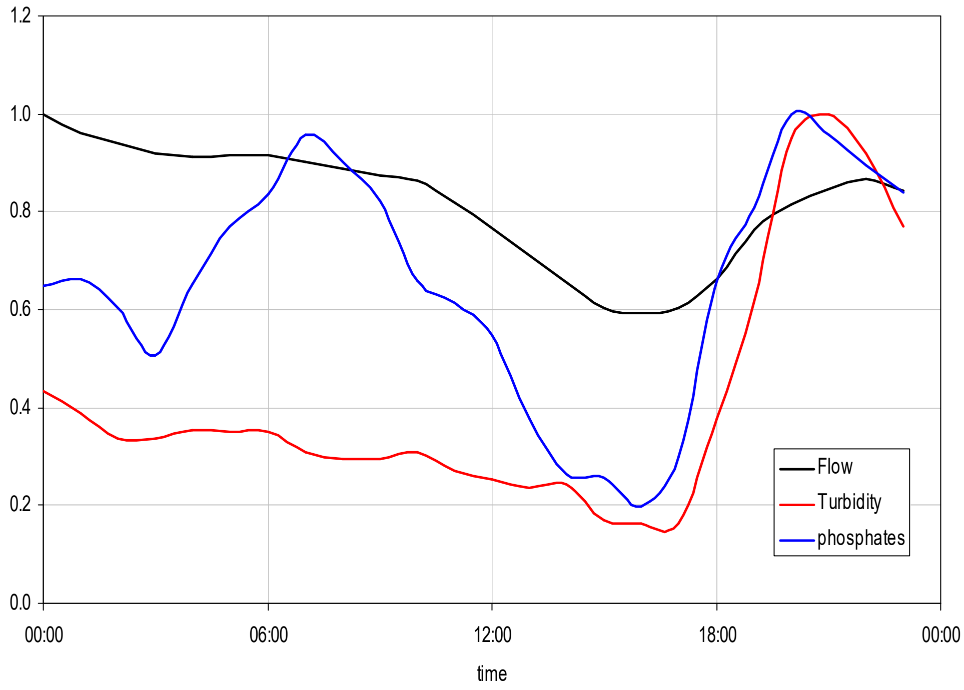


Case II: Coagulant Dosing Control

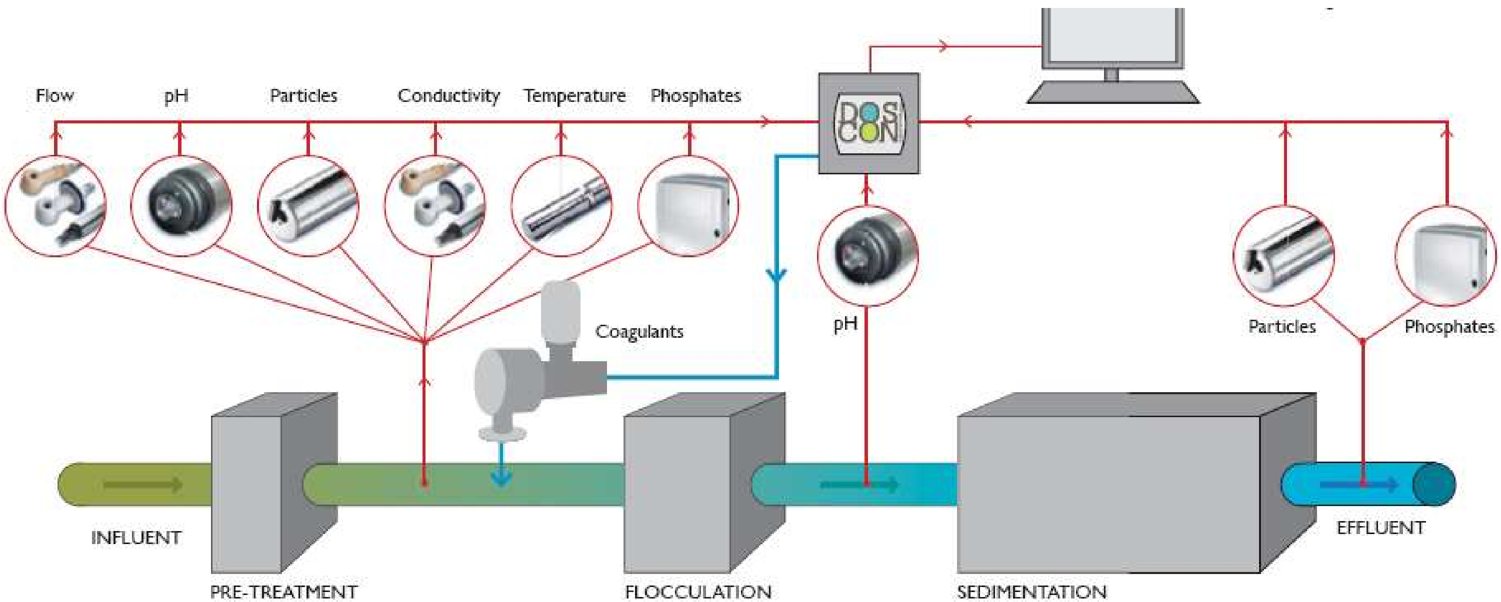
Flow Proportional Dosing

Most DWTPs and WWTPs use flow proportional dosing

… but water quality parameters vary not proportionally to each other



Multi-parameter based optimal dosing control

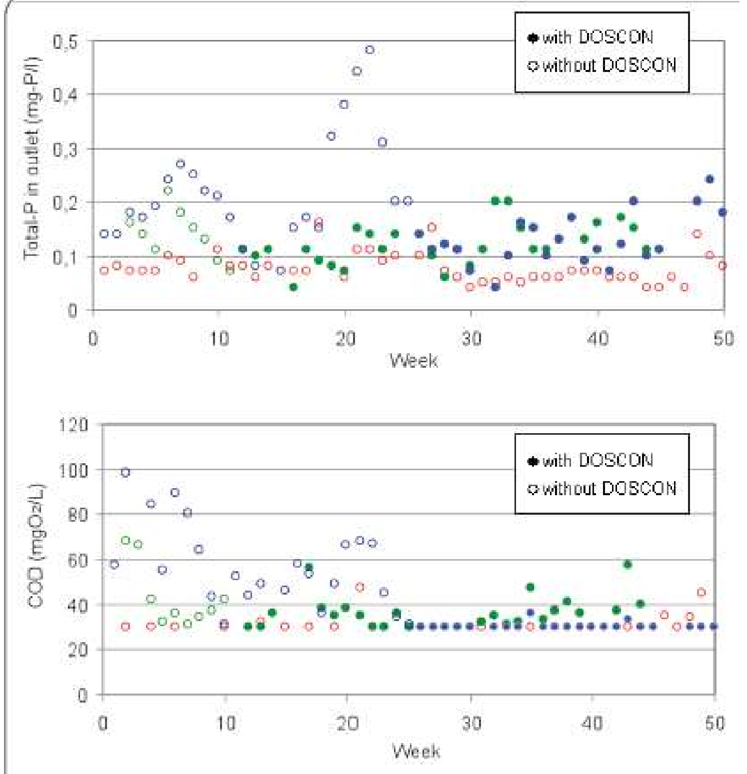


D=f(Q, pH, P, SS, temp, Cond, etc)

Energy Savings with dosing control

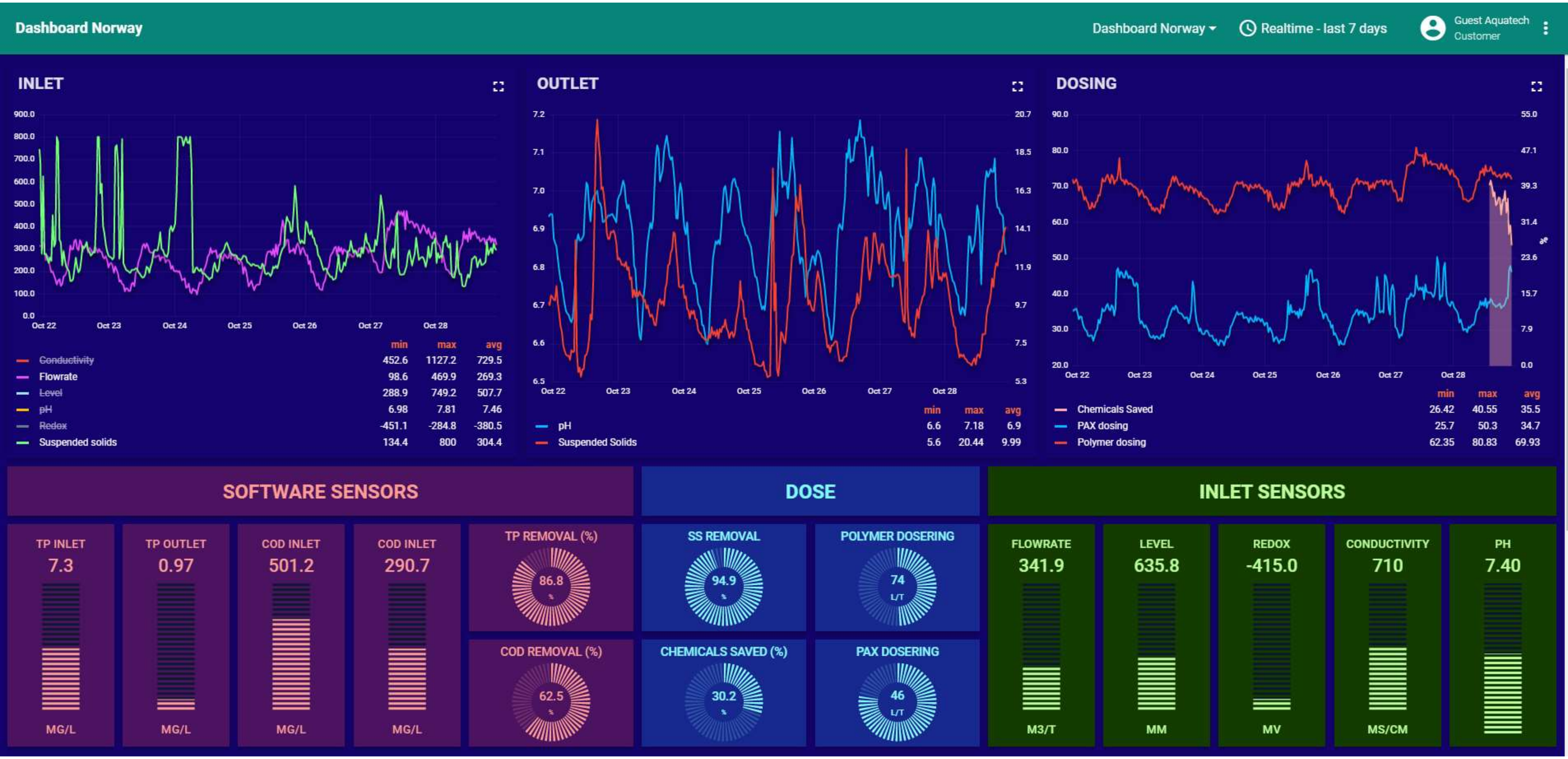
11 years of full scale results: 32% reduction of coagulants

Coagulant costs = 300,000 USD/year
Savings= 100 000 USD/year
(Q=50 000m3/d)

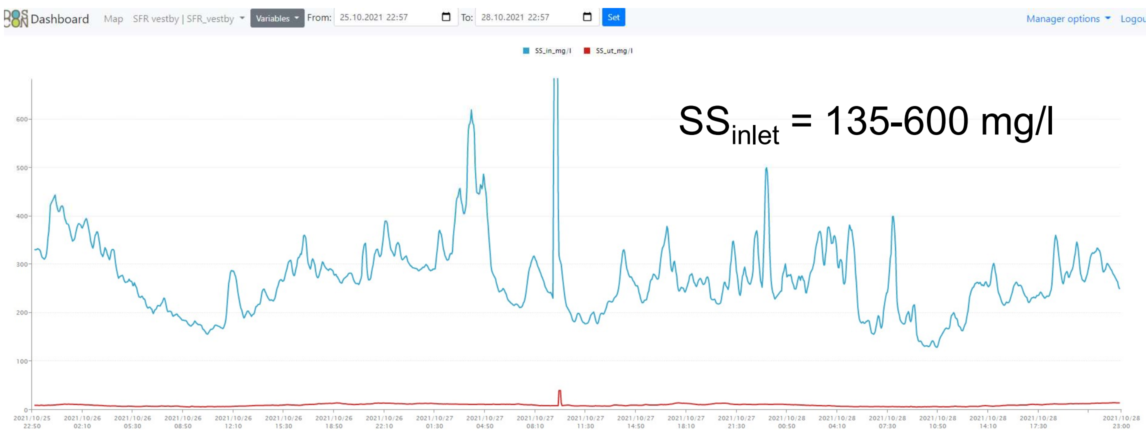


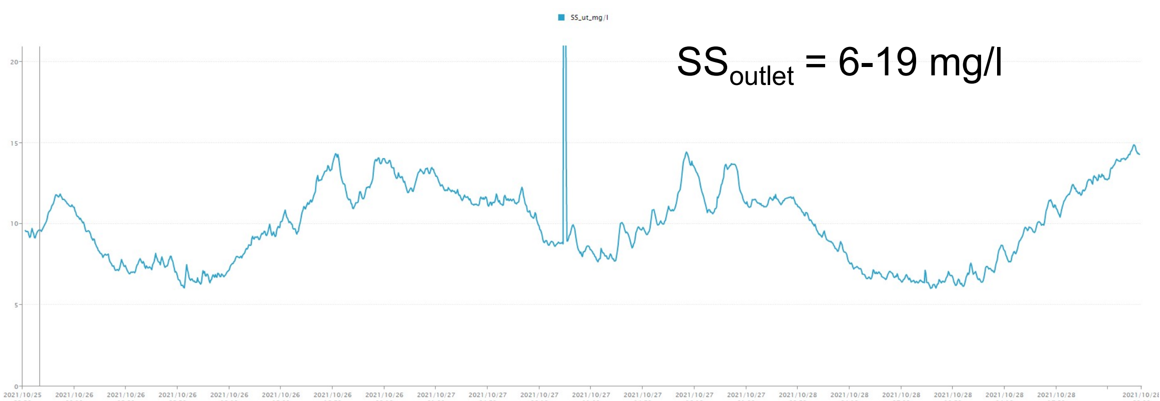
Open circles shows the results before DOSCON and closed circles with DOSCON in operation during 2008 (red), 2009 (green) and 2010 (blue). DOSCON almost always gave outlet Total-P values below 0.2 mg-P/l (middle figure) and COD values below 60 mgO$_2$/l (bottom figure), while reducing >20% of coagulants.

Virtual sensors – example



Process optimization: example





>70% removal of COD with no biological processes