Control possibilities in wastewater treatment

Gustaf Olsson
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Università Degli Studi di Palermo
13 March 2014

Content

- Introduction - why ICA – (Instrumentation, Control and Automation)
- A basic activated sludge plant
- The energy issue
- Disturbances
- The role of control and automation
- Examples of control applications
- Monitoring
- Plant wide control

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ICA – Instrumentation, Control and Automation

- The system is dynamic
- Using real time sensors – ”to measure is to know”
- Feedback – drive the process towards high performance all the time
- Maximize efficiency

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Why monitoring and control?

- Variable influent (disturbances)
- Effluent requirements
  → Consistent operation
  1. Keep the plant running – control equipment
  2. Satisfy the limits
  3. Minimize the costs
- Economic gains in design
- Economical gains in operation
  – Saving energy and chemicals

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Driving forces – demand pull

- Regulatory requirements
- Energy efficiency
- Nutrient recovery
- Heat recovery
- Biogas production
- Disturbance resilience

ICA impact on design

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Driving forces - technology

- Instrumentation
- Computer revolution
  - From kilobytes to gigabytes
  - Data acquisition
  - Model representation
  - Generations of SCADA systems
- Networking and Internet
- Actuators and power electronics

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Saving resources and energy

- Saving energy
  - Dissolved oxygen control
  - Pumping control
  - Coordination of many unit processes
  - Optimal sequencing in sequential batch reactors
- Saving chemicals
  - Dosage control
- Producing more biogas energy
  - Monitoring and control of AD

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7

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Towards more ICA in wastewater treatment

Only C removal
Less restrictive legislation
Few instruments
Little economic incentive

Chemical P removal
Gradually stricter legislation
More computing power
Better model understanding

Biological N and P removal
More elaborate effluent rules
On-line nutrient measurements
Advanced model knowledge
Increasing economic pressure
Education

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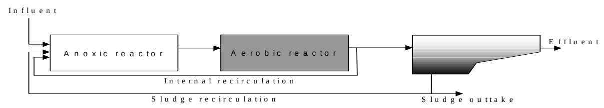
Pre-denitrification plant



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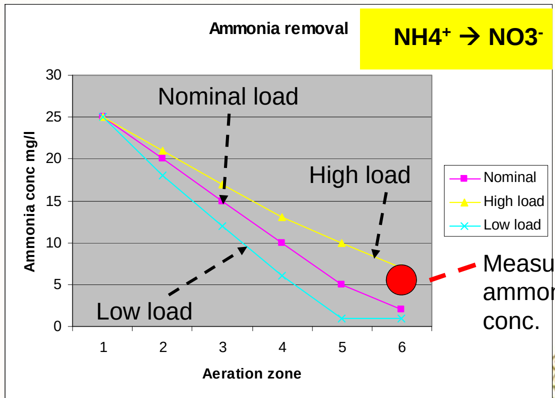
10

Ammonia concentration along the aerator - *oxidation*



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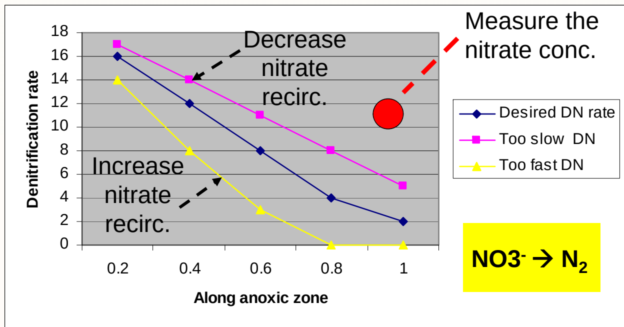
11

Nitrate concentration along the anoxic zone - *reduction*



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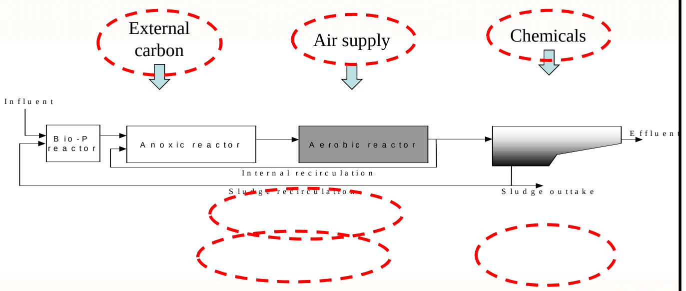
12

Plant design for bio-P removal



Control actions have different costs

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13

14

Aerator

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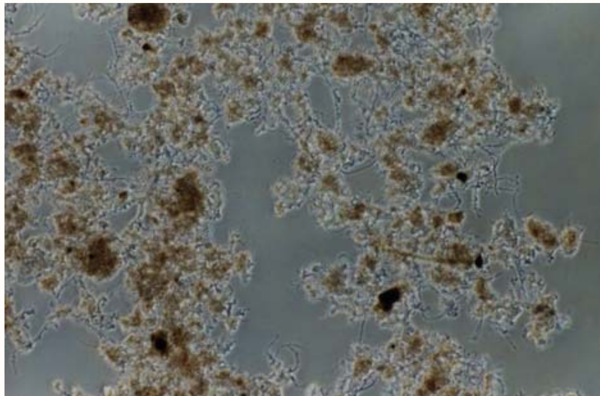
15

Sludge in microscope



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16

Content

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- **The energy issue**
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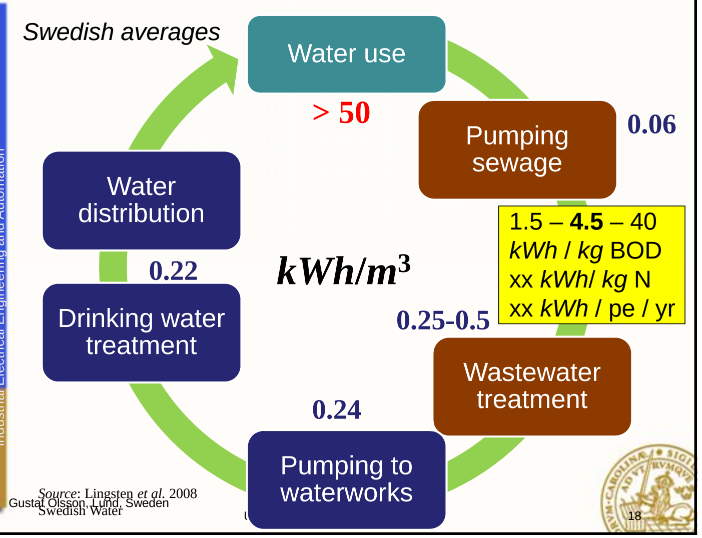

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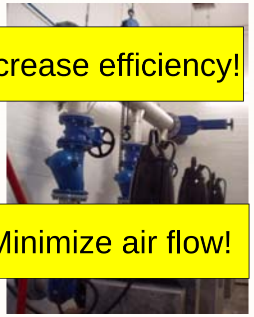
Clean Water Requires Energy!

- **Pumping**
  - **Having efficient pumps for adequate flows**
  - **Operating at dynamically changing flows and pressures**
- **Aeration in wastewater treatment**
  - **Adequate compressors**
  - **Controlling the air flow for variable loads**

Increase efficiency!

Minimize air flow!



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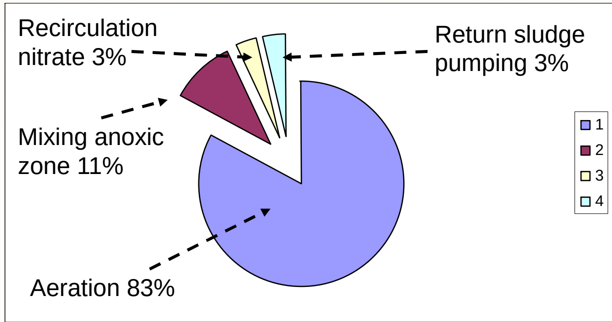
Electrical energy for the Biological Plant

Some German data (100 000 pe)



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Future water supplies ….

…will be more energy intensive

Readily accessible fresh water supplies are limited and have been fully allocated in some areas

➡ Increased energy for pumping (deeper – longer)

New technologies to access/treat water will use more energy

➡ Impaired, reused, brackish, sea water

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21

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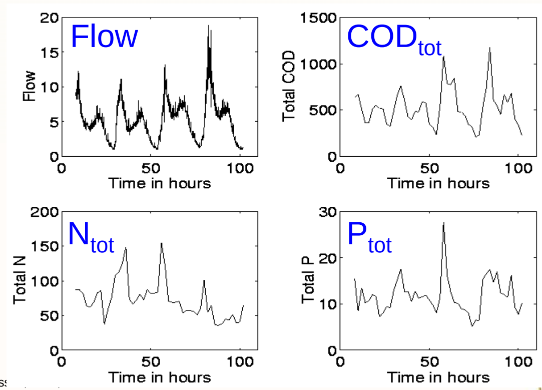
22

Disturbances – influent small WWTP



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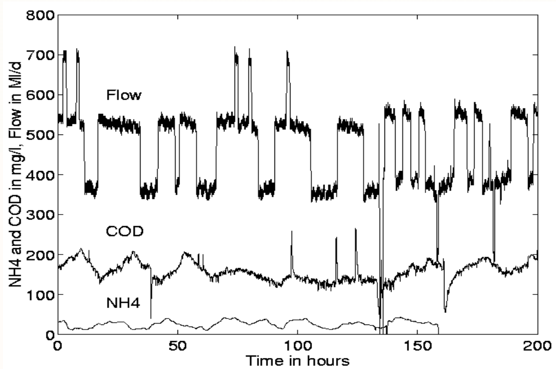
23

Disturbances – influent large WWTP



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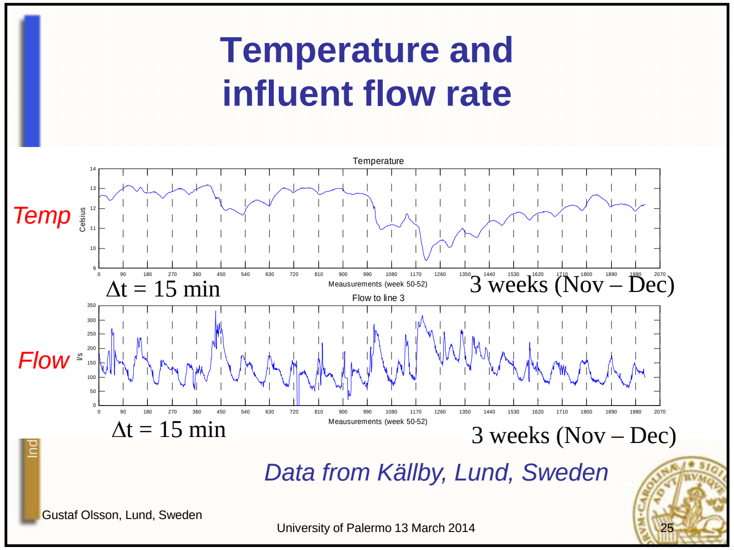
24


Temperature and
influent flow rate
Temperature
Temp
Celsius
Δt = 15 min
Measurements (week 50-52)
3 weeks (Nov – Dec)
Flow to line 3
Flow
l/s
Δt = 15 min
Measurements (week 50-52)
3 weeks (Nov – Dec)
Data from Källby, Lund, Sweden
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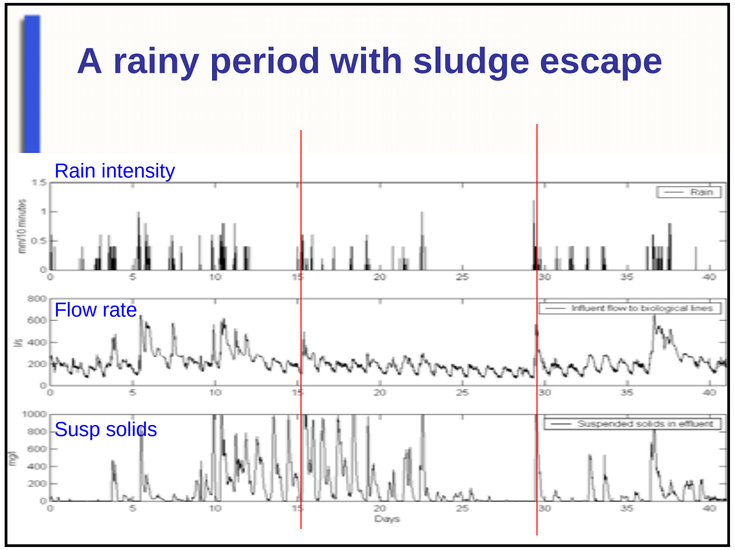
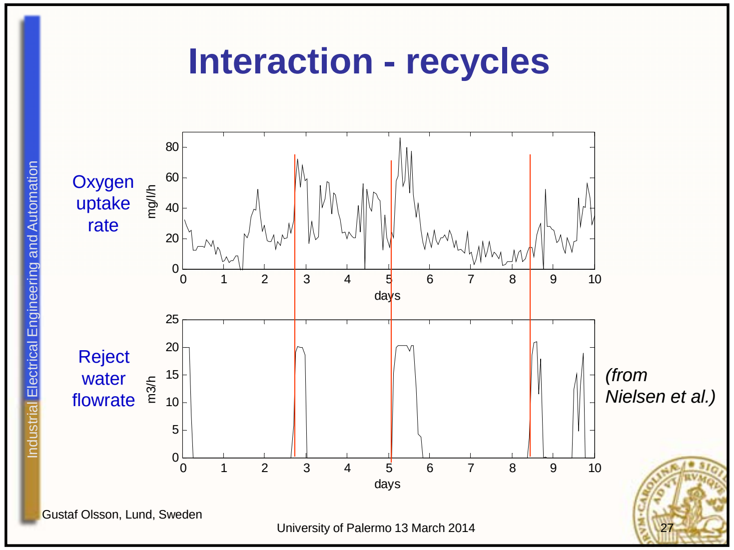
25


A rainy period with sludge escape
Rain intensity
mm/10 minutes
Rain
Flow rate
l/s
Influent flow to biological lines
Susp solids
mg/l
Suspended solids in effluent
Days


Interaction - recycles
Oxygen
uptake
rate
mg/l/h
days
Reject
water
flowrate
m3/h
days
(from
Nielsen et al.)
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27


Water supply - pipe failure
Burst – an event
Leak – a condition
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Content

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- Disturbances
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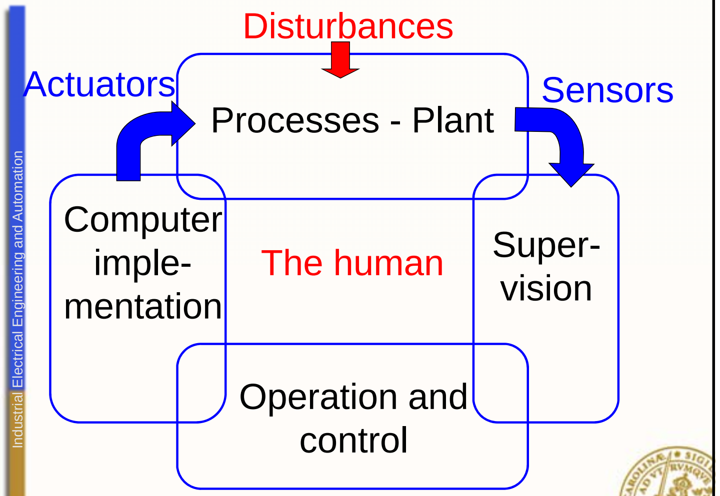

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Time Scales of Control in WWTP

Days - months – strategies	***Management***
Days - weeks – biomass growth	***Supervisory control***
Hours to days – concentration dynamics – nutrient removal	***Advanced process control***
Minutes to hours – flow dynamics – dissolved oxygen	***Basic control***

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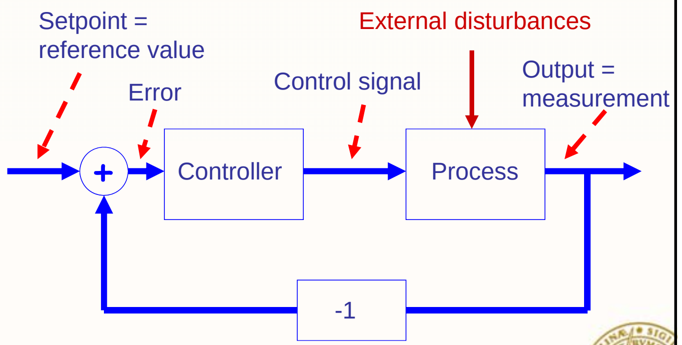
Simple feedback control



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Levels of control and automation– example water systems

- **Keep the plant running**
  - Control of machinery: motors, pumps, valves, etc.
- **Satisfy the ”product” quality**
  - Satisfy effluent quality regulations
- **Minimize the cost and maximize the efficiency**
  - Minimize electrical power use, chemicals, etc.

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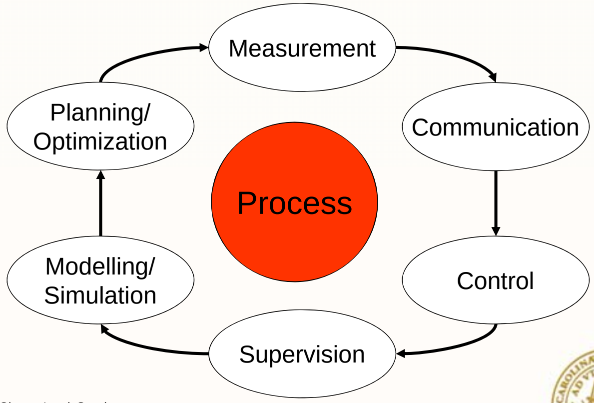
33

Aspects of automation



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Added controllability (1)

- **Bioreactors – anaerobic, anoxic, aerobic zones**
- **More sophisticated air supply**
  - Separate control of zones
  - Variable pressure control
- **More intermittent systems (SBR)**
- **Aerated tank settling operation**

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Added controllability (2)

- **More recirculations**
  - e.g. nitrate recirculation
- **Chemicals added**
  - enhanced primary clarification
  - chemical P removal
- **Volatile fatty acids**
  - enhance Bio-P
- **External carbon**
  - control denitrification

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36

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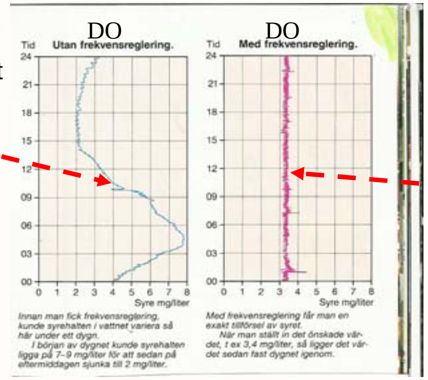
DO control using variable speed compressors

Without speed control



(Bo Brink, Laholm)

With speed control

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DO sensors

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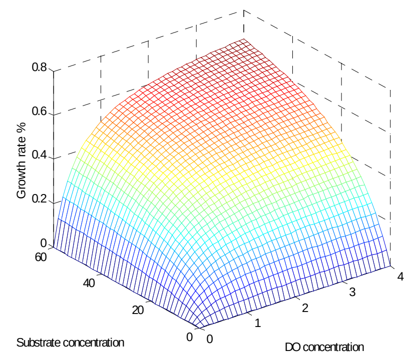
Growth rate as function of substrate & DO concentrations



K_o=1
K_s=20

Matlab: monodcurve3d

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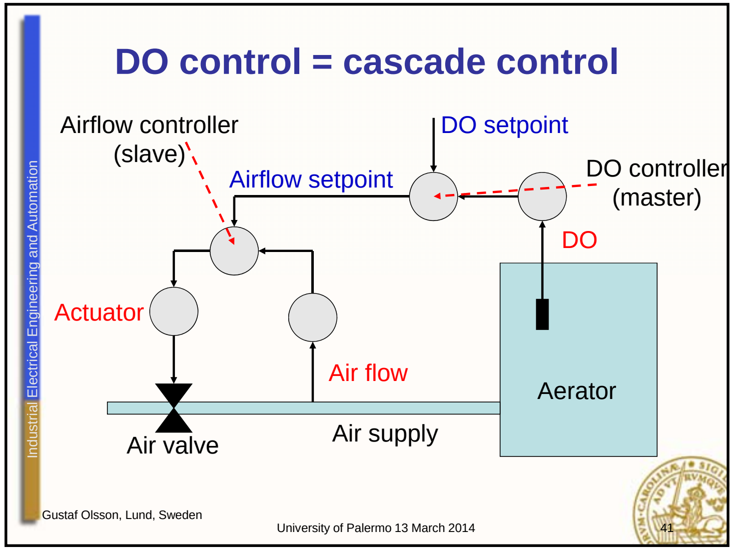
DO control = cascade control
Airflow controller
(slave)
DO setpoint
Airflow setpoint
DO controller
(master)
DO
Actuator
Air flow
Aerator
Air valve
Air supply
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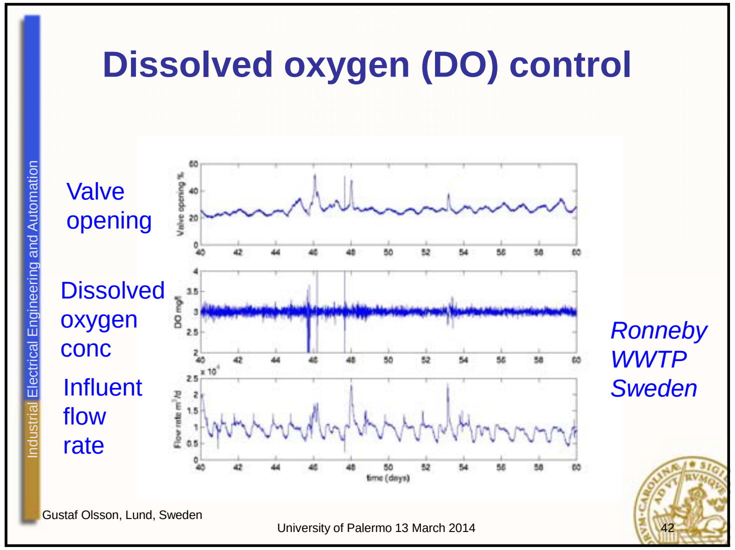
41


Dissolved oxygen (DO) control
Valve
opening
Dissolved
oxygen
conc
Influent
flow
rate
Ronneby
WWTP
Sweden
time (days)
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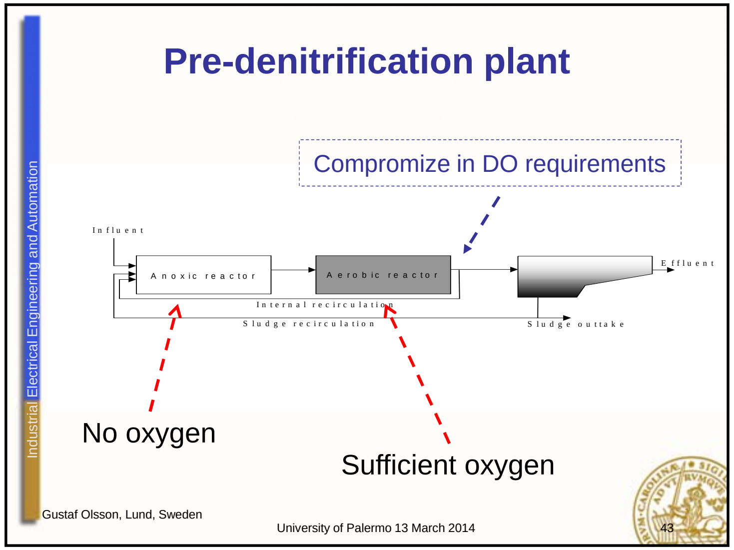
42


Pre-denitrification plant
Compromize in DO requirements
Influent
Anoxic reactor
Aerobic reactor
Effluent
Internal recirculation
Sludge recirculation
Sludge outtake
No oxygen
Sufficient oxygen
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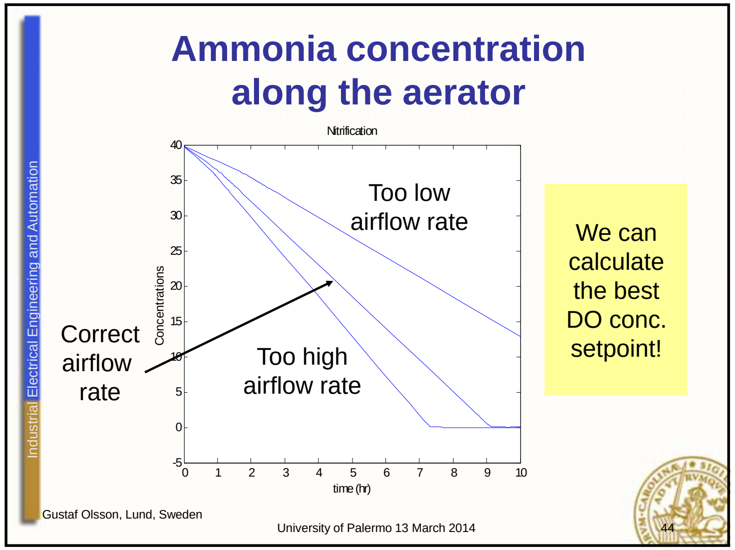
43


Ammonia concentration
along the aerator
Nitrification
Too low
airflow rate
Correct
airflow
rate
Too high
airflow rate
Concentrations
time (hr)
We can
calculate
the best
DO conc.
setpoint!
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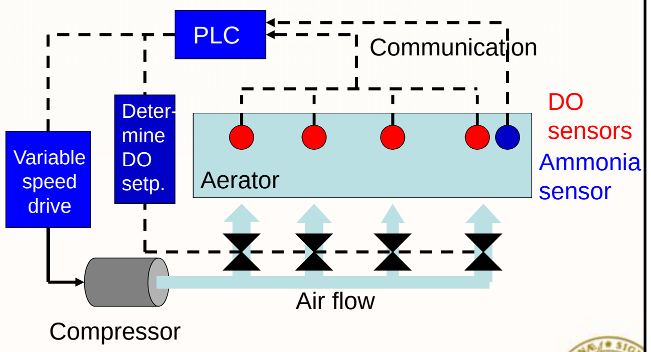
44

Aeration – closed loop control – DO setpoint control



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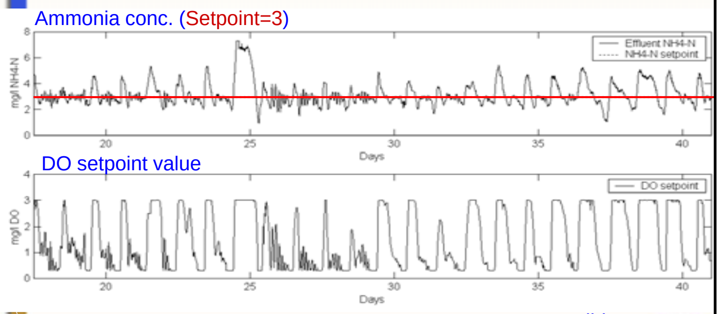
45

Performance of NH_4 based DO controller



Variable DO setpoint → further 10-15% savings

Ingildsen

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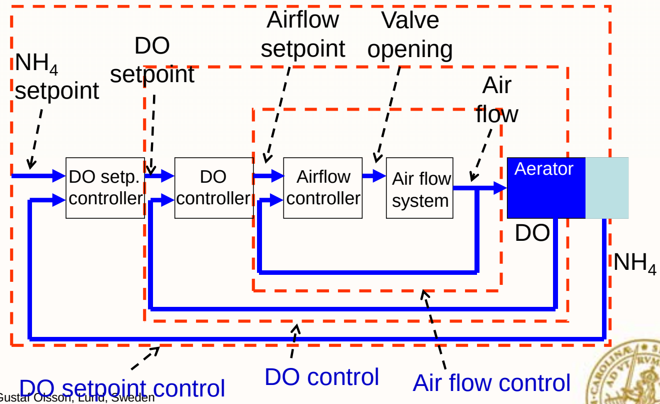
46

Variable DO setpoint control



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47

Unit process control

- **DO control**
  - **Hundreds of papers since the 1970s**
  - **How complex controller is needed?**
  - **Controlling the DO profile**
  - **DO setpoint control (ammonia sensor)**
- **Nitrate recirculation**
- **Return sludge, sludge age**
- **Dosage control (Ext. C, chemicals)**

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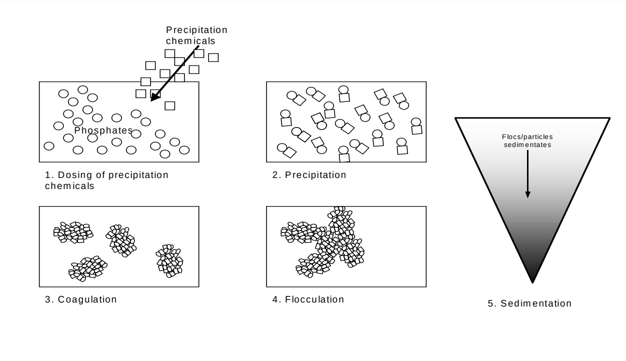
48

P removal using chemical precipitation – principle



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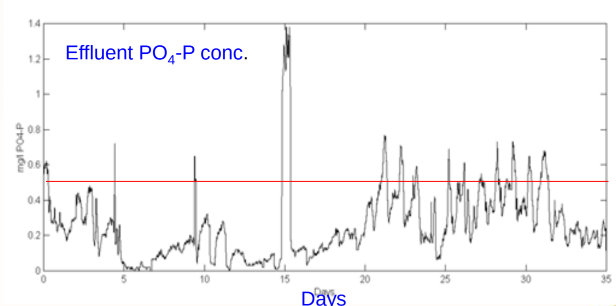
49

Chemical dosage – based on hydraulic load



Ingildsen

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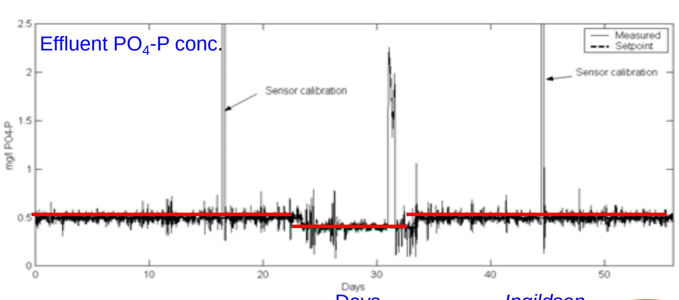
50

Chemical dosage – based on P sensor feedback



Saving 36% chemicals

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51

Content

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- **Disturbances**
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Instrumentation today

- Almost 100 sensor companies working with water
- Sensor networks
  - Data fusion
  - Internet – the ubiquitous control room

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Process monitoring (1)

- All measurements need to be tested and verified!
- Cross-check
- Automatic actions in alarm situations
- Often thousands of "simple" measurements
  - Binary sensors
  - Simple physical measurements

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54

Process monitoring (2)

- **Track** important variables and states in the process and to relate their values to a reference or "baseline"

→Updated knowledge on the process state

- **Detect** deviations in the performance of the process
- **Isolate** the source of the deviation

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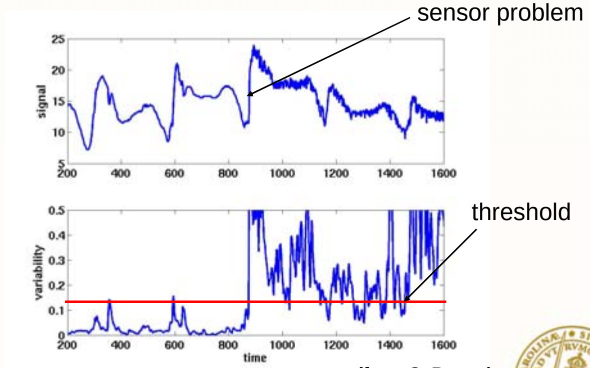
55

Example - variability



(from C. Rosen)

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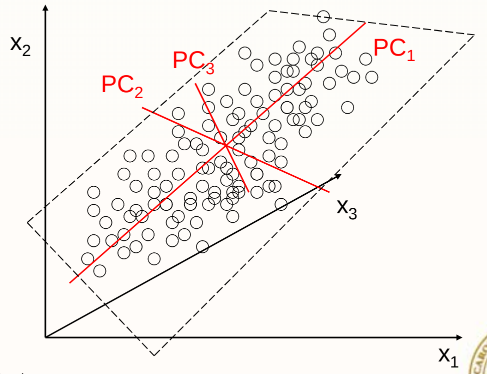
56

Process monitoring (3)

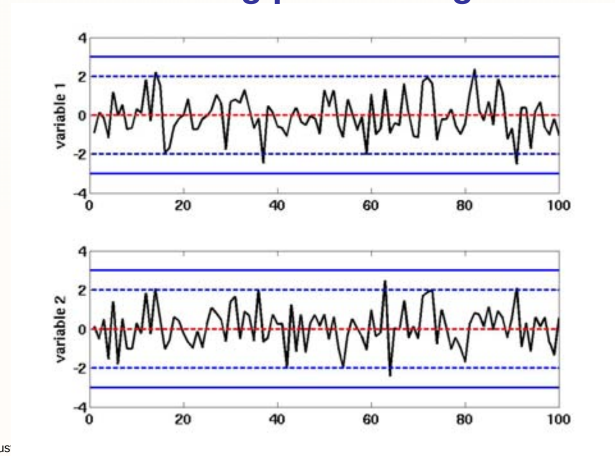
- **Univariate monitoring**
  - Analysis of an individual signal or measurement.
- **Multivariate monitoring**
  - Analysis of several signals or measurements and their mutual relationships

Look for abnormal behaviour

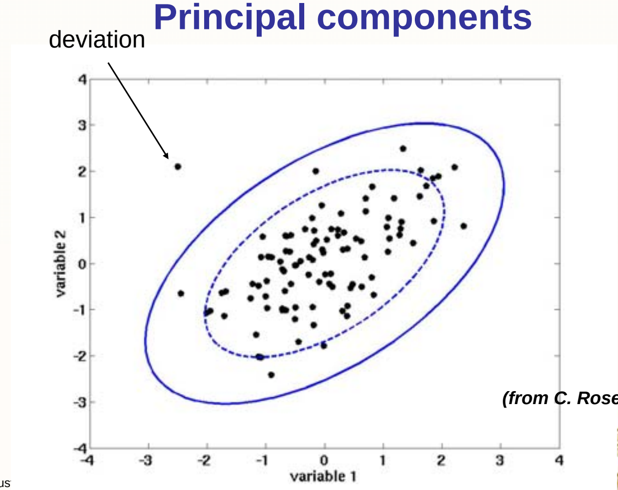
PCA – Principal Component Analysis



Monitoring process signals

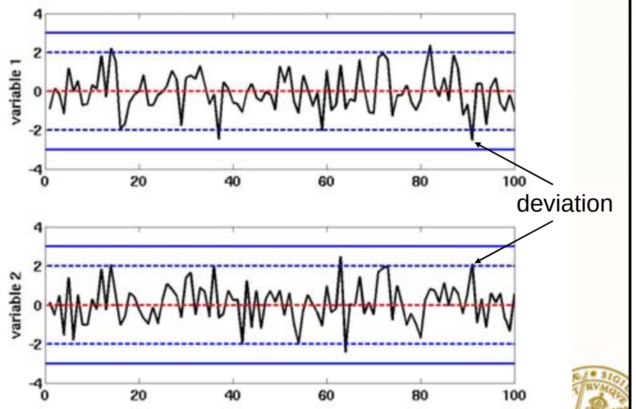


Principal components



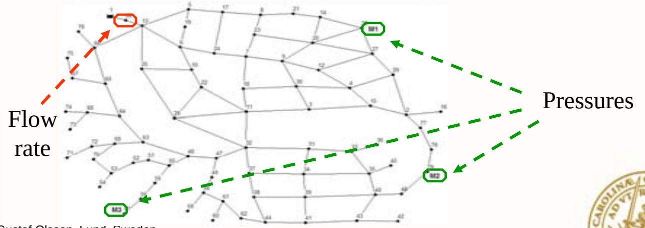
(from C. Rosen)

Detecting deviations



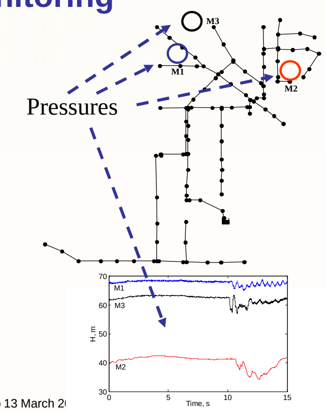
Water Supply
Steady-state analysis-based failure monitoring

- ***Permanent* installation for *continuous* break monitoring**
- ***Applicable in the DMA setup***
- ***Flow* at the entry and *pressure* at selected locations measured**
- ***Detection and location* of nodal and non-nodal bursts**
- ***Condition – demand information is available and the model of the system is calibrated***



Water Supply
Unsteady-state analysis-based failure monitoring

- ***Permanent installation for continuous burst monitoring***
- ***Condition – the burst induces a transient wave***
- ***Immediate detection and location of nodal and non-nodal bursts***
- ***Location error less than 10 m***
- ***Can be combined with steady-state approach***



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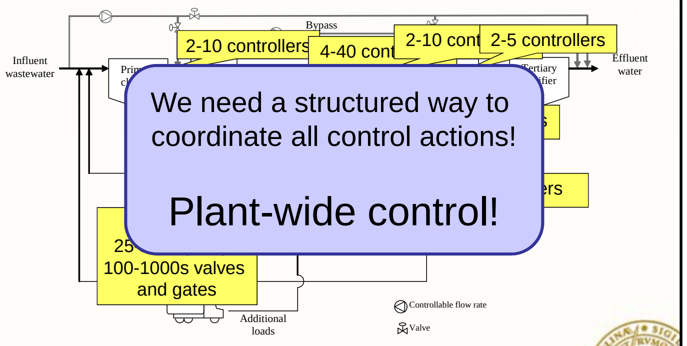
- **Plant wide control**

Plant-wide control



(from C. Rosen)

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System wide control

Kukudis, 1973:

"We must speak of automation in the entire system -- the network of sewers and the plants".

Sewer control was applied in Cleveland in the early 1970s

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Why plant wide?

- **Energy efficiency**
- **Where to use the carbon**
- **Influence of recirculations**
- **Relate sludge production to desired gas production**
- **Handle varying loads – disturbance rejection strategies**
- **Minimize influence on receiving waters**

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Approaches to plant wide

- **Development towards integrated modelling**
- **Decision support systems (DSS) to deal with complexities of decision making**
  - **Math models**
  - **Control algorithms**
  - **Knowledge-based techniques**
    - **Experience from operators**
    - **Existing databases**

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Compromize

Sewer operation:
Minimize the combined sewer overflow (CSO)

WWTP operation:
Satisfy the effluent requirements
Minimize the operational cost

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Integrate design and control

Make use of new **instruments**: bioreactors, settlers, sewers, anaerobic processes

Computers: Take advantage of the huge storage capacity and processing capacity

Signal treatment & monitoring: Exhaust the information, operator support, automatic detection

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Control: which complexity is needed?

System wide control:
How to formulate criteria?
Handle the complexity of couplings.
Making user friendly systems.

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ICA in the whole water cycle:
Non-conventional water systems.
The automated decentralized WWTP
Drinking water treatment.
Smart water grids.
Water reuse

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Automation because…

- Disturbances are everywhere
  - Compensate for them
- On-line sensors no longer the main limitation for on-line control
- Data acquisition – monitoring
  - Early warning
- Control
  - Saving energy and resources
  - Producing energy
  - Consistent operation

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The control challenge

- Understanding the process
- Making the best use of sensors
  - Control structure
- Having actuators with sufficient control authority
- Exhaust the measurement information
- Understanding the control criteria

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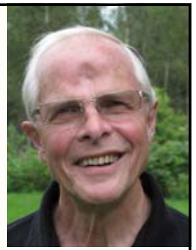
Contact…



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