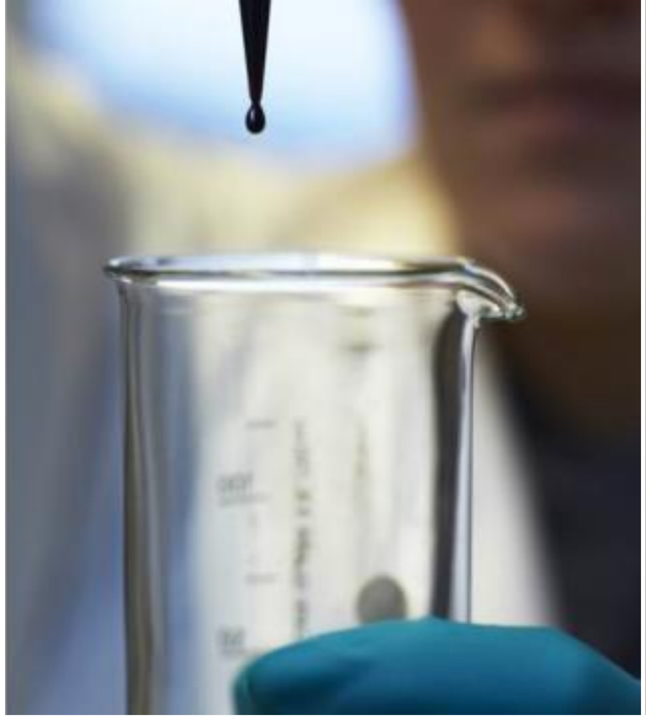
DEVELOPING A PROCESS MODEL FOR ÄNGENS WWTP



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October 2019

RISE Research Institutes of Sweden

Urban Water Management

RISE Research Institutes of Sweden

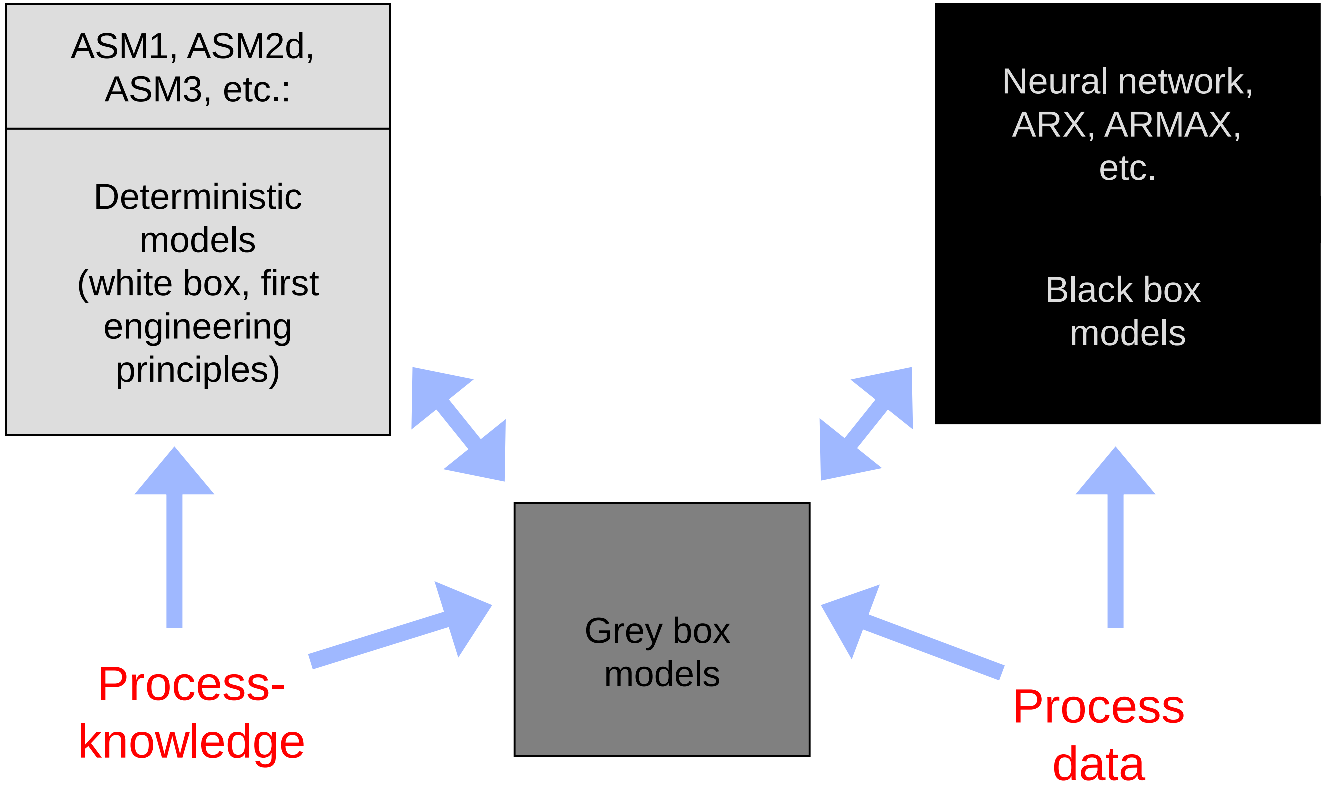
- Swedish government owned research institute
- Close collaborations with academia and industry in innovation projects
- Group Urban water management
  - Focus on decision support tools within the all aspects of urban water management
  - Sub group specialized in modelling and simulation of wastewater treatment systems

Outline

- What are WWTP process models and why use them?
  - Introduction
  - Purpose of project
  - Goals
- Uncertainty
- Planned activities
  - Simulation platform
  - Model structure
  - Wastewater characterization measurements: total ww and industry ww
  - Literature review
  - Sensitivity analysis
- Questions/comments

What is a process model and why use it?

Model types


ASM1, ASM2d, ASM3, etc.:
Deterministic models (white box, first engineering principles)
Neural network, ARX, ARMAX, etc.
Black box models
Grey box models
Process-knowledge
Process data

Model structure

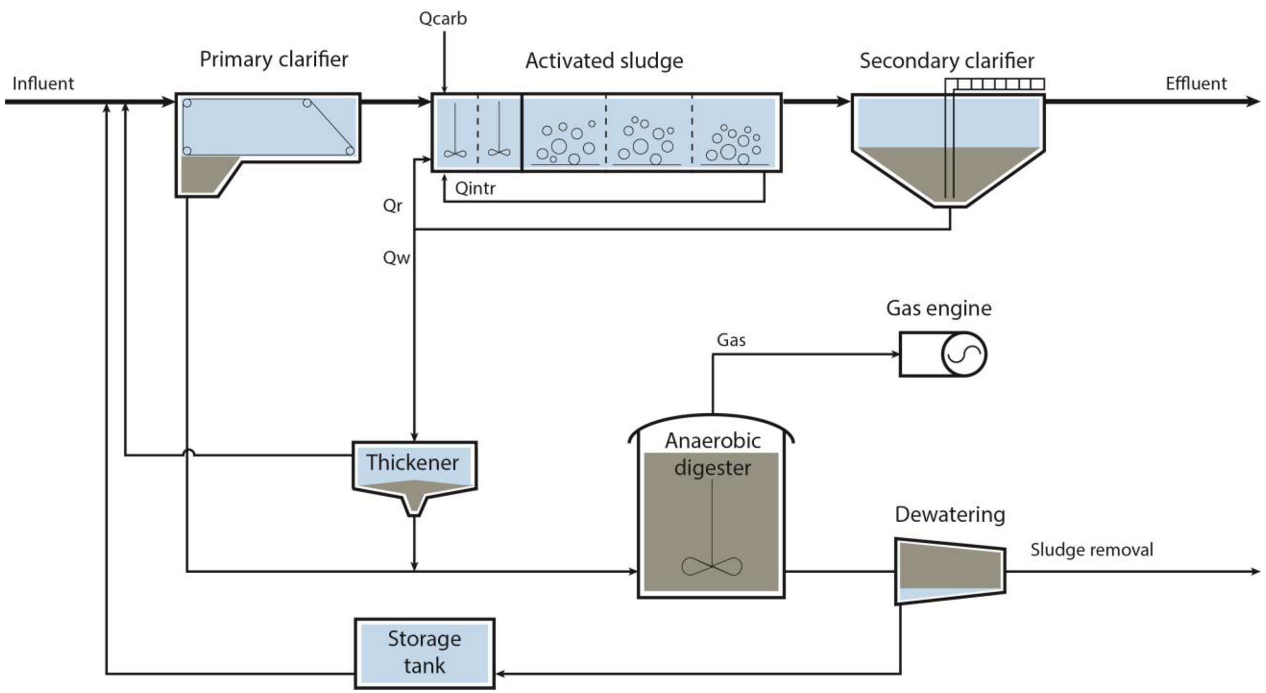
- State variables
  - Concentration in reactor
- Parameters
  - E.g. organism growth rate
- Assumptions
  - Constant reactor volumes
  - Completely mixed reactors

- Mass balance equations
  - (in - out) = (consumption – production)
- Initial/boundary conditions

WWTP process model

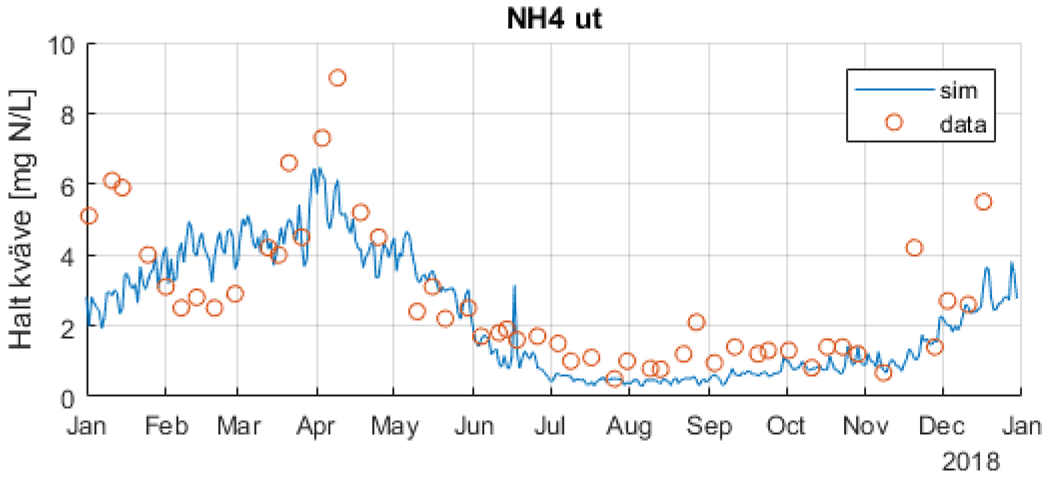
- Hydraulics
- Biological processes
- Chemical processes
- Physical processes

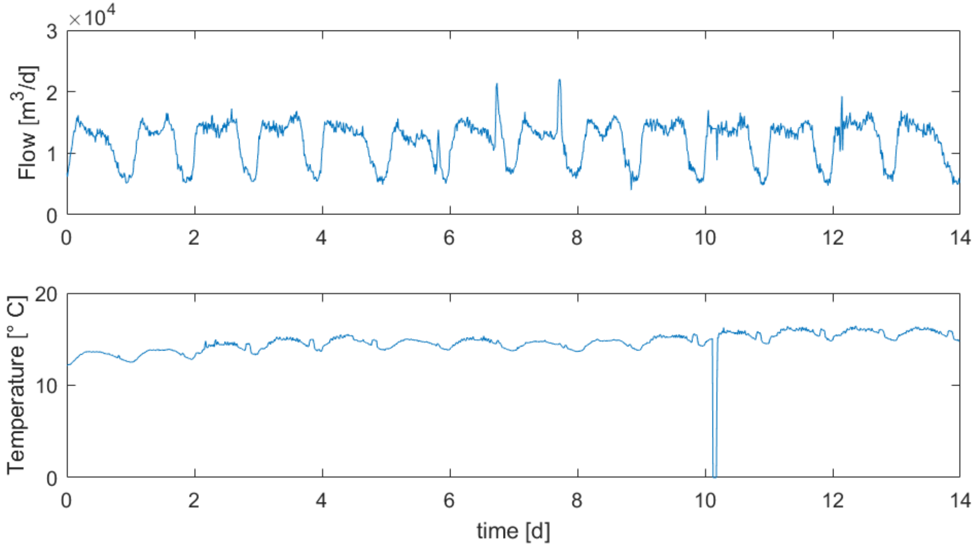
- Sub-models
  - Activated sludge
  - MBBR
  - Anaerobic digestion
  - Sedimentation
  - Etc



Static vs dynamic models

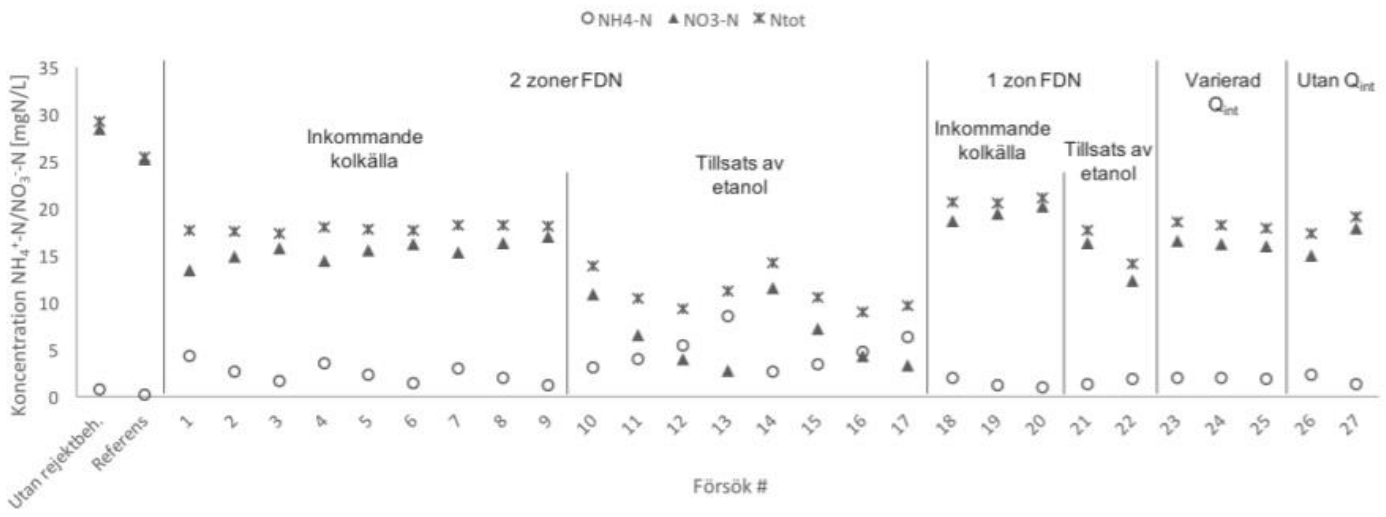
- Static (steady state) models: static with respect to time
- Dynamic models: varying with respect to time





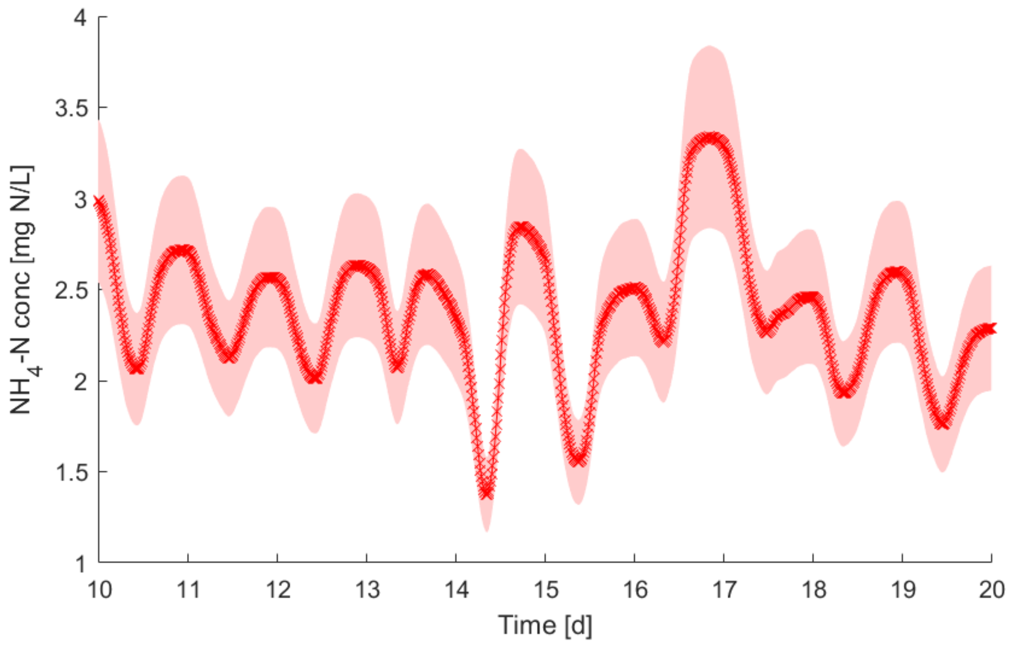
Why use wastewater treatment process models?

- Municipal wastewater treatment plants never in steady state
  - Some phenomena hard to capture with static models => dynamic model required
- More detailed description of wastewater composition
- Optimization -> ability to test advanced control strategies
- Quantification and visualization of results



Why use wastewater treatment process models?

- Modern WWTP complex, many recirculating streams => feedback effects
- Use as learning tool for new staff
- Process understanding
- Plant understanding
- Quantification of uncertainty



Purpose and goals

Purpose of project

- Verify static design
  - Detailed wastewater characterization
  - Dynamic input (time varying flow and pollutant loads)
  - Quantification of uncertainties
- Develop a platform for education of plant staff
- Verify models for nutrient recovery
  - Allow other plants to use the models to predict potential benefits of the process with higher degree of confidence

Goals

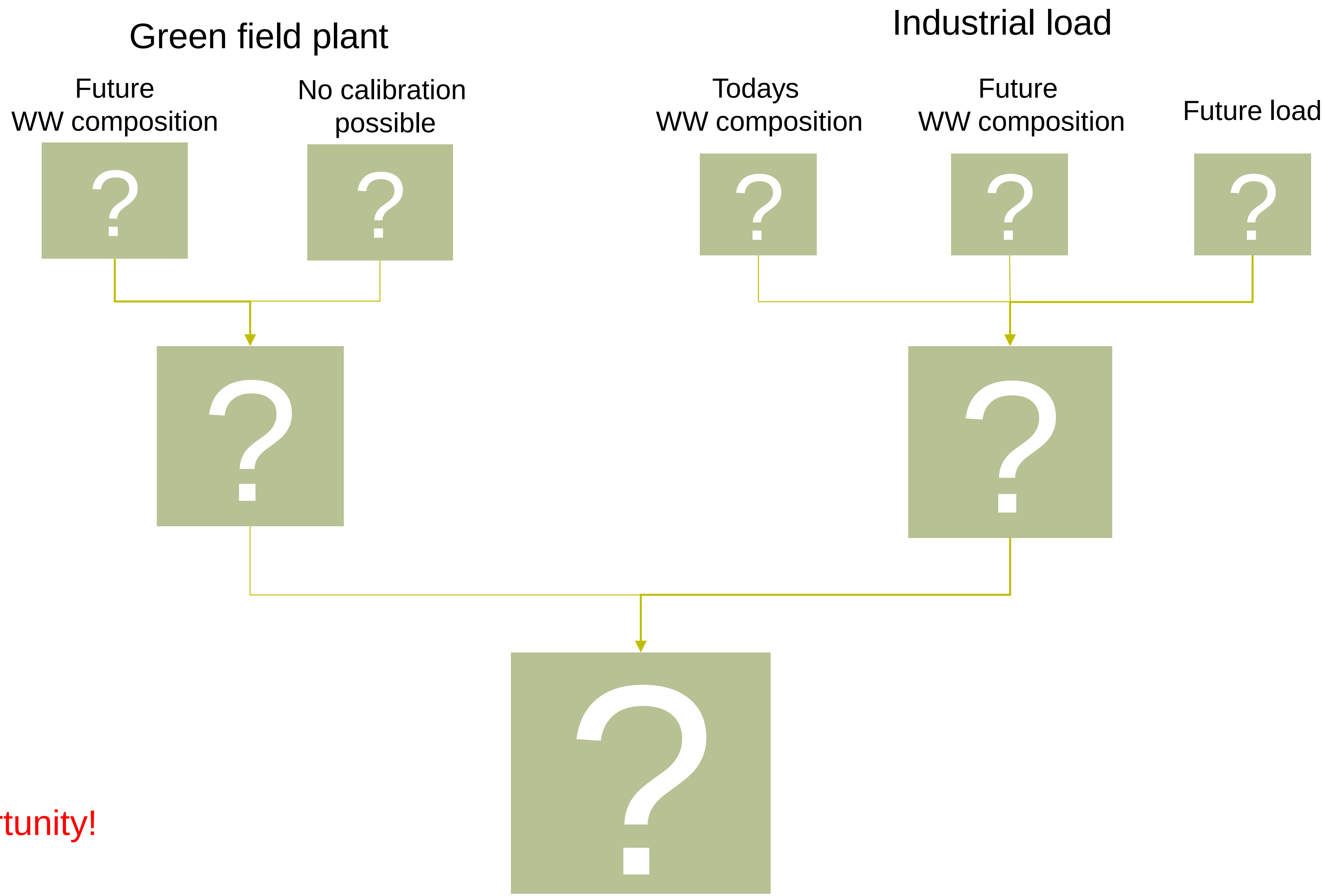
1. Develop a process simulation model for the future wastewater treatment plant, including the following processes:
   - Water line:
     - Primary settler
     - Activated sludge with EBPR
     - Secondary settler
     - Ozone treatment + MBBR
     - Chemical precipitation
     - Disc filters
   - Sludge line:
     - Thickening and dewatering
     - Anaerobic digestion
     - Sludge aeration
     - Sludge anoxic zone
     - Hydrolysis
   - Resource recovery
     - Struvite precipitation

Goals

2. Use the model to verify static design and compare to effluent demands through simulation of 4 scenarios
   - Design load, dry year (1 full year of simulation)
   - Design load wet year (1 full year of simulation), including maximum hydraulic load
   - Shock load from industry discharge
   - High flow situations occurring at extreme rain events
3. Identify uncertain model parameters through literature review, including:
   - Biological process parameters
   - Wastewater characterization parameters
4. Quantify uncertainty through sensitivity analysis

Uncertainty

Uncertainty



Model = opportunity!

Planned activities

What will be done?

- Measurements and analysis => heavy focus on characterization of the current wastewater and separation of the industrial load (Reppe) from the total
- Literature review
- Sensitivity analysis
- Simulation platform: Sumo, by Dynamita

Model structure

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Model structure

- Mechanistic model, i.e. based on understanding of mechanisms of process behaviour
- Includes biochemical and chemical processes
- Biochemical model based on biomass growth (Monod kinetics) for EBPR and COD/N-removal
- ”Super”-model structure, meaning single model for all type of reactors, operating conditions determine biomass proliferation in each reactor

Model structure – state variables (selected)

Volatile fatty acids (VFA)	COD
Readily biodegradable substrate (non-VFA)	COD
Colloidal biodegradable substrate	COD
Slowly biodegradable substrate	COD
Soluble unbiodegradable organics	COD
Colloidal unbiodegradable organics	COD
Particulate unbiodegradable organics	COD
Stored polyhydroxyalkanoates (PHA)	
Stored glycogen (GLY)	
Ordinary heterotrophic organisms (OHO)	Biomass
Phosphorus accumulating organisms (PAO)	Biomass
Glycogen accumulating organisms (GAO)	Biomass
Aerobic ammonia oxidizers (AOB)	Biomass
Nitrite oxidizers (NOB)	Biomass

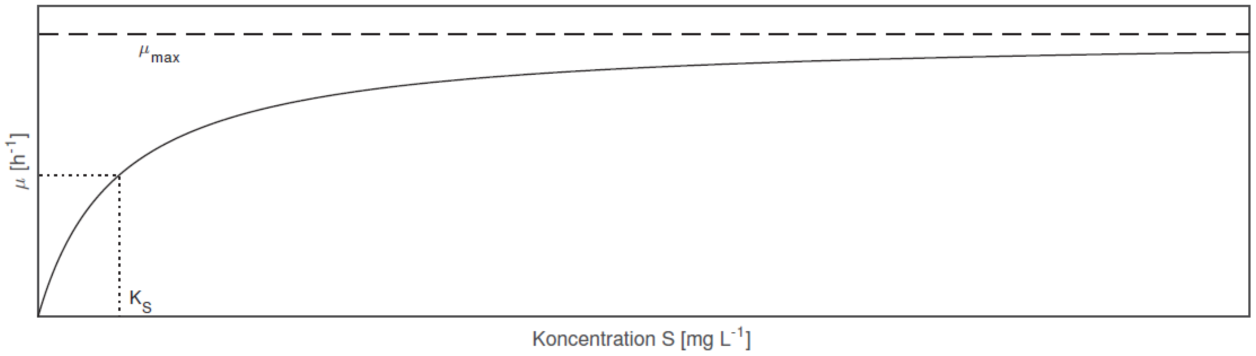
Total ammonia (NHx)	N fractions (not all)
Nitrite (NO2)	N fractions (not all)
Nitrate (NO3)	N fractions (not all)
Orthophosphate (PO4)	P fractions (not all)
Stored polyphosphate (PP)	P fractions (not all)
Dissolved oxygen (O2)	
Total inorganic carbon (CO2)	pH calculations
Other strong cations (as Na+)	pH calculations
Other strong anions (as Cl-)	pH calculations
Calcium	pH calculations
Magnesium	pH calculations
Potassium	pH calculations
Hydrogen sulfide (H2S)	pH calculations
Sulfate (SO4)	
Calcium carbonate (CaCO3)	
Struvite (STR)	

Model structure – bio-kinetics

- Monod growth kinetics for biomass

$$\mu = \mu_{max} * \frac{S_S}{S_S + K_S}$$

Monod term



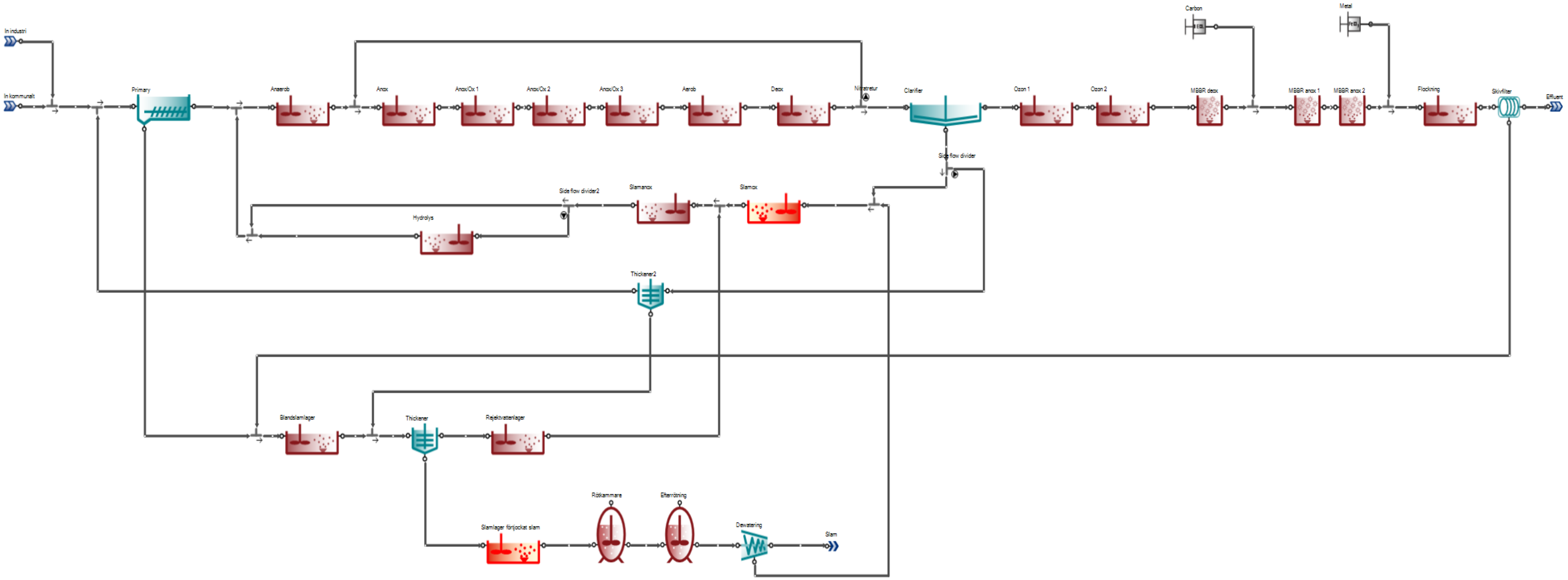
Model structure – processes & parameters

- EBPR activated sludge
- Chemical P removal
- MBBR
- Settling
- Thickening/dewatering
- Digestion

- Ozonation not included, needs to be coded

- Excel

Model structure

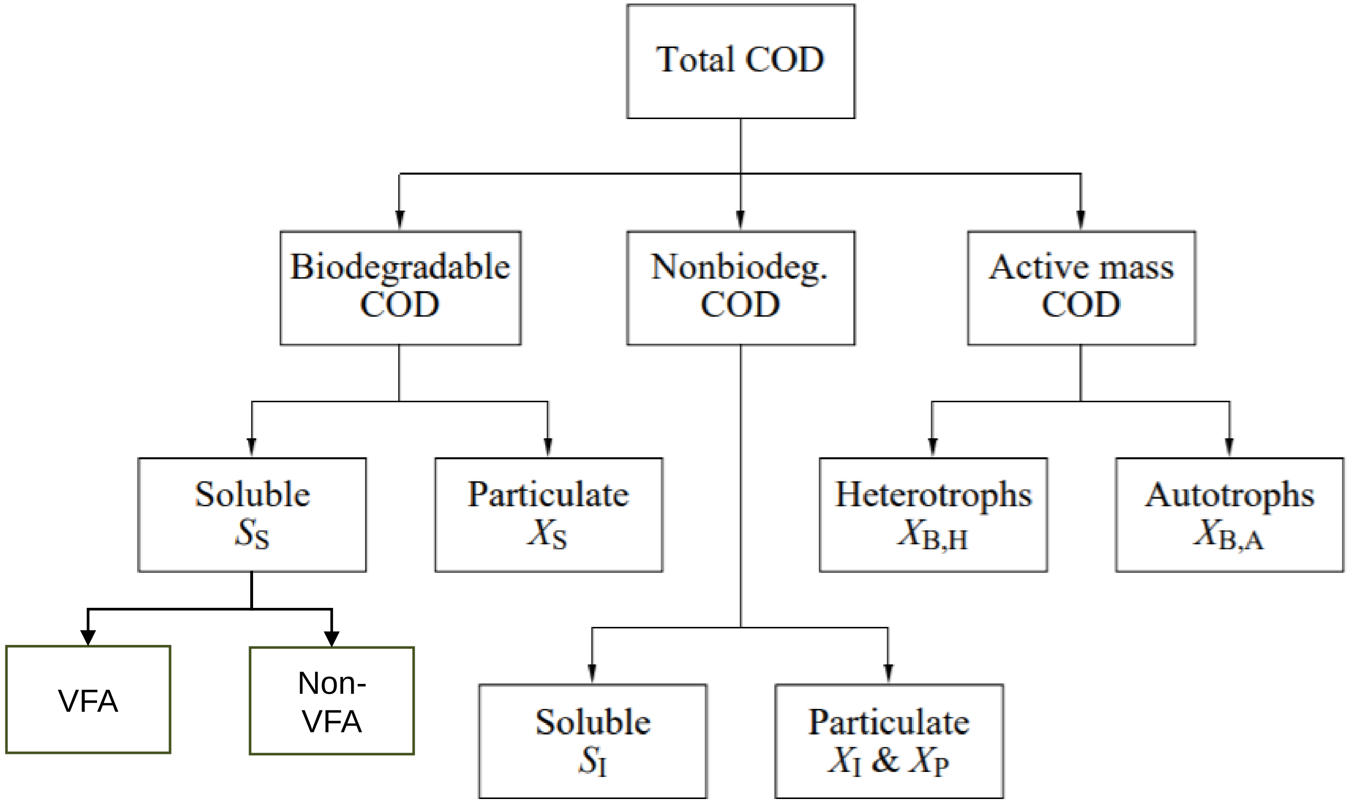


Wastewater characterization

Wastewater characterization – what does it mean?

- Detailed distribution of measured pollutants into model fractions

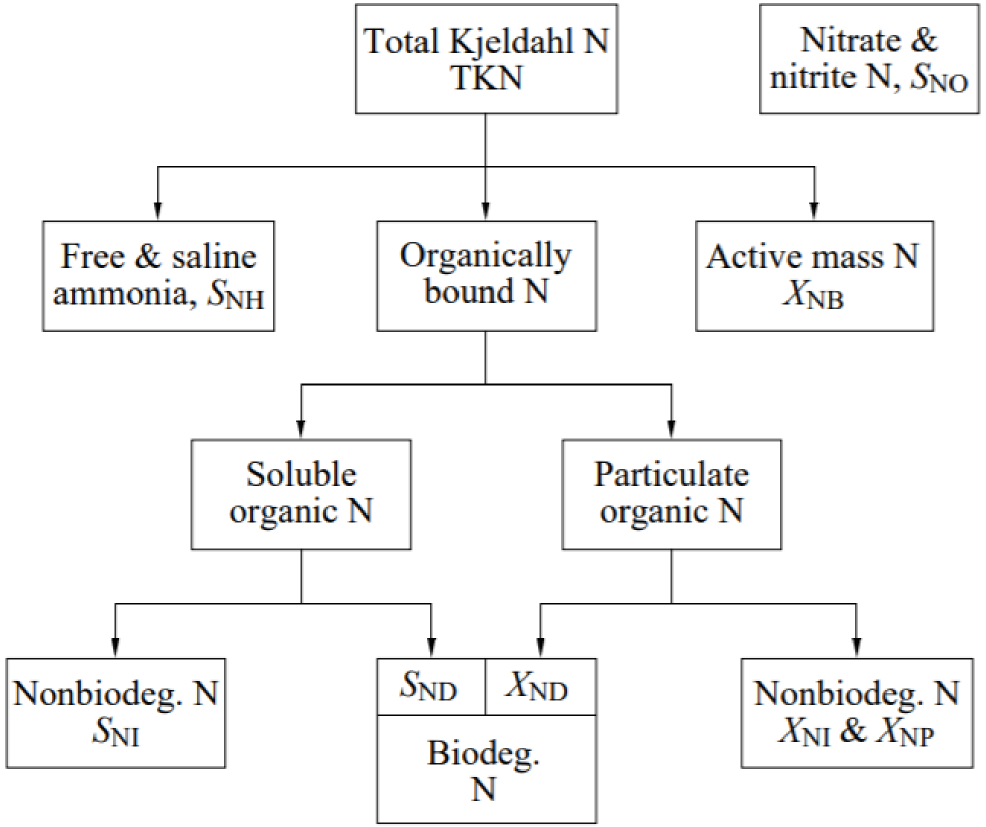
COD



Wastewater characterization – what does it mean?

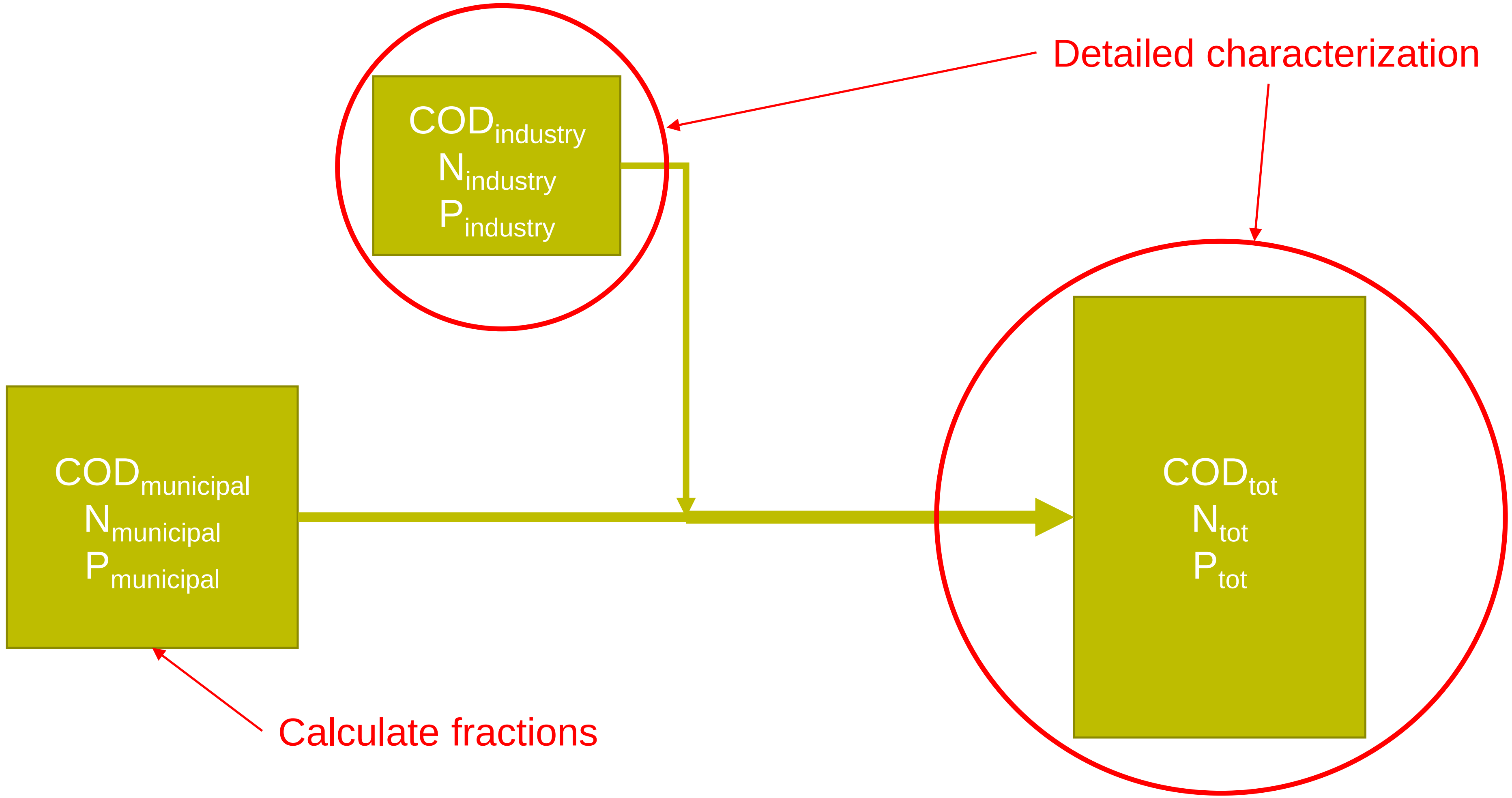
- Detailed distribution of measured pollutants into model fractions

Nitrogen



Wastewater characterization

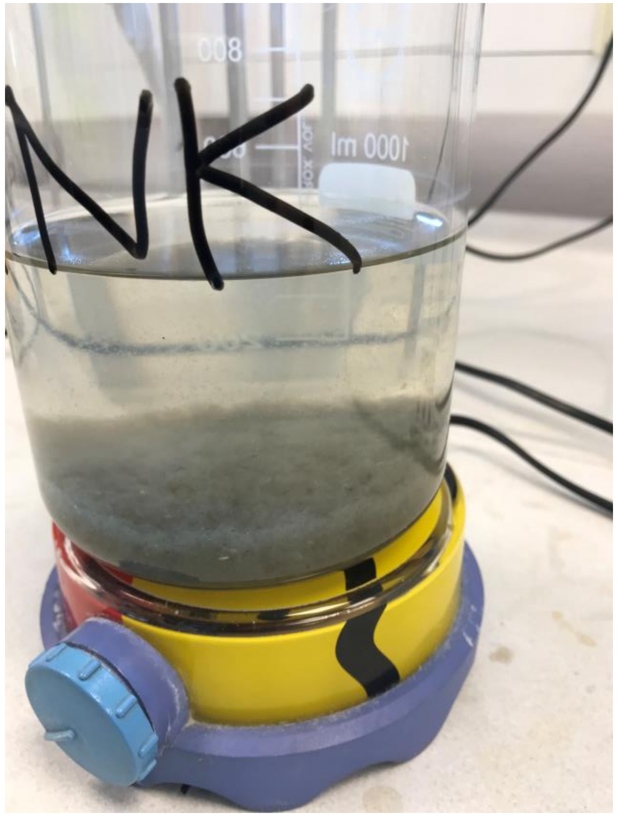
- Incoming and industrial load measured and characterized
- Municipal load calculated



Wastewater characterization – inflow current WWTP

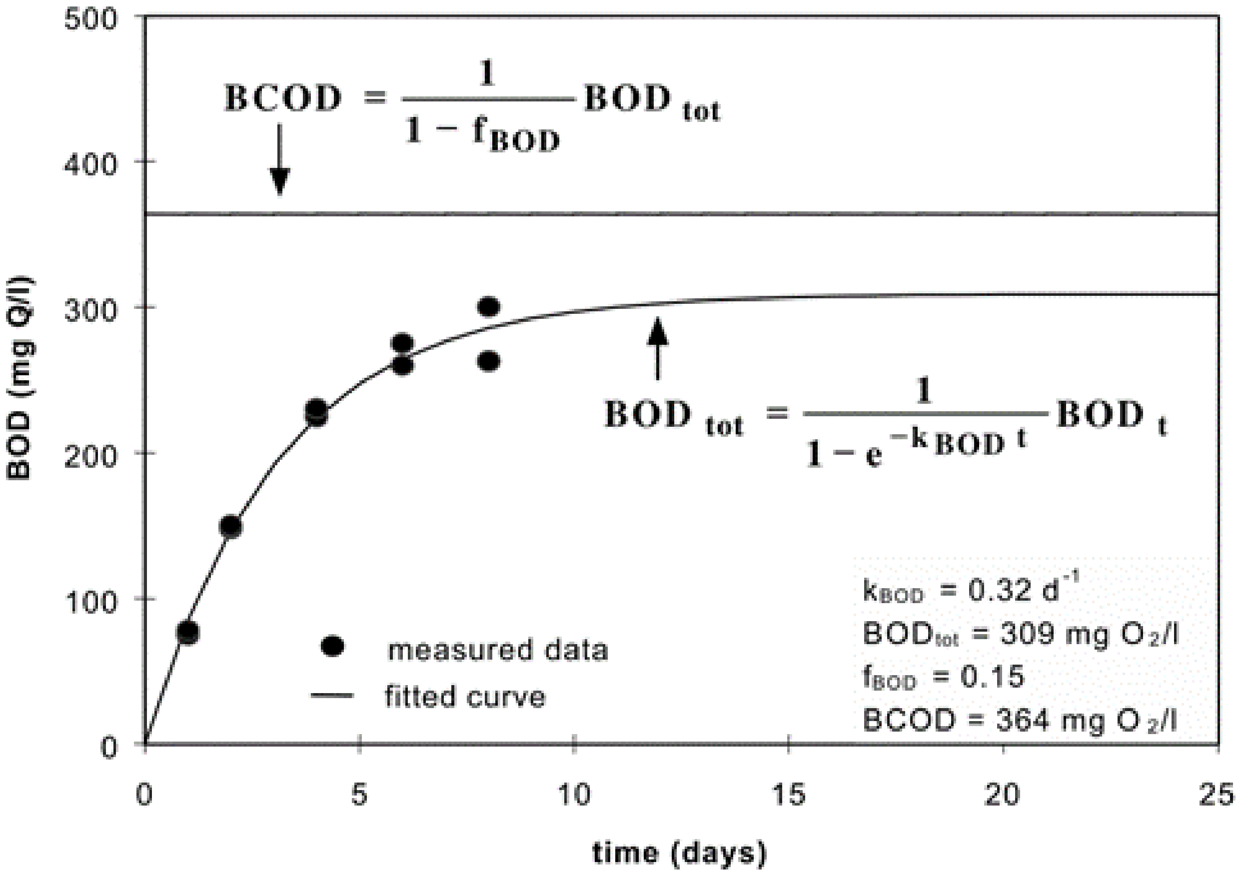
- Physio-chemical characterization method:
  - Measure raw sample
  - Add flocculation chemical, let settle, filter (0.45 µm filter) influent and effluent, then measure

Parameter	Unit	Influent WWTP	Effluent WWTP	Industry
COD_{tot}	mg O_2/L	x	x	x
COD_{filt}	mg O_2/L	x	x	x
$COD_{floc,filt}^{*}$	mg O_2/L	x	x	x
VFA	mg VFA/L	x		x
BOD_7	mg O_2/L	x	x	x
$BOD_{1,2,5,7,9}$	mg O_2/L	x		
N_{tot}	mg N/L	x	x	x
$N_{tot,floc,filt}$	mg N/L	x	x	x
NH_4-N	mg N/L	x	x	x
NO_2-N	mg N/L	x	x	x
NO_3-N	mg N/L	x	x	x
P_{tot}	mg P/L	x	x	x
$P_{tot,floc,filt}$	mg P/L	x	x	x
PO_4-P	mg P/L	x	x	x
TSS	mg SS/L	x	x	x
VSS	mg SS/L	x	x	x
Alkalinity	varies	x	x	x
pH	-	x	x	x



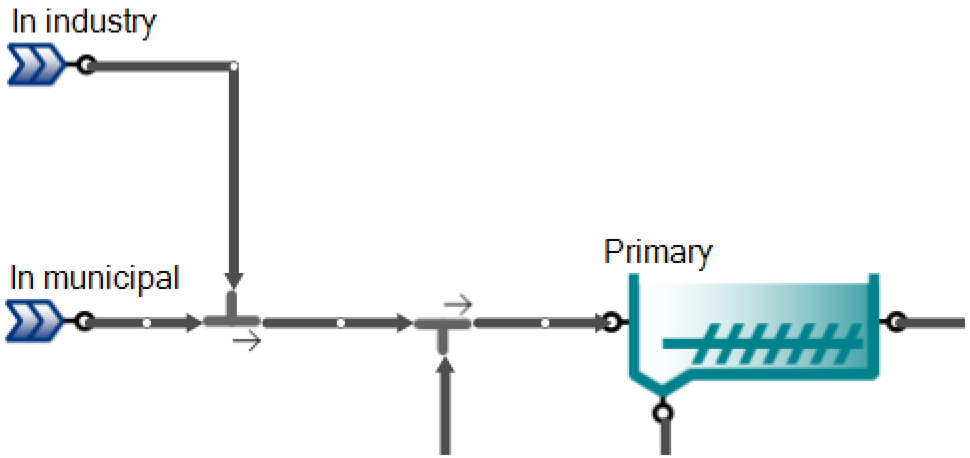
Wastewater characterization – inflow current WWTP

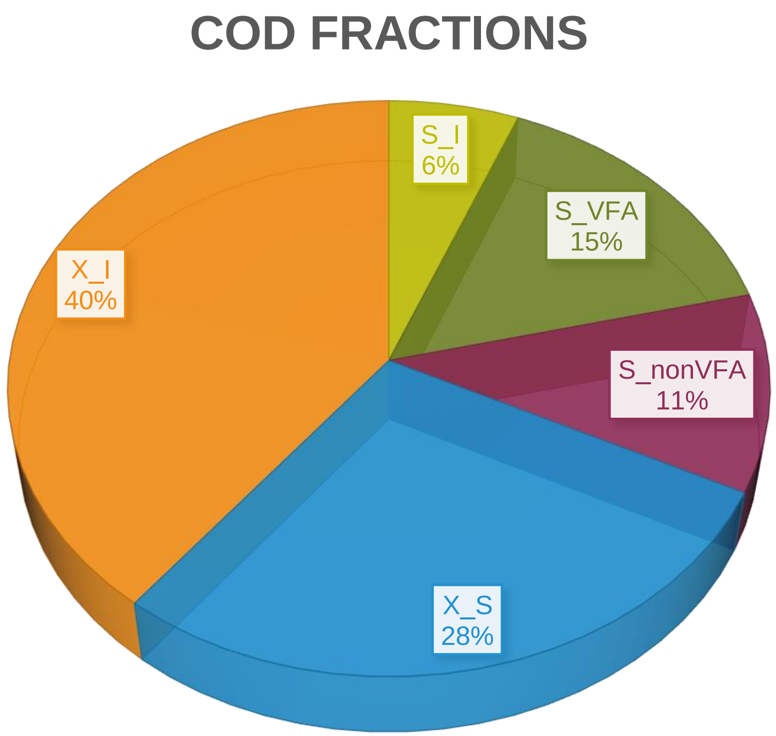
- BOD-test over several days
- Total biodegradable COD-fraction



Wastewater characterization – inflow current WWTP

- Daily average (flow proportional data)
- Separate results for industrial and municipal





Wastewater characterization – Industrial WW

- Harder to characterize than municipal wastewater
- Biological batch tests probably needed
- Measure dissolved COD over time

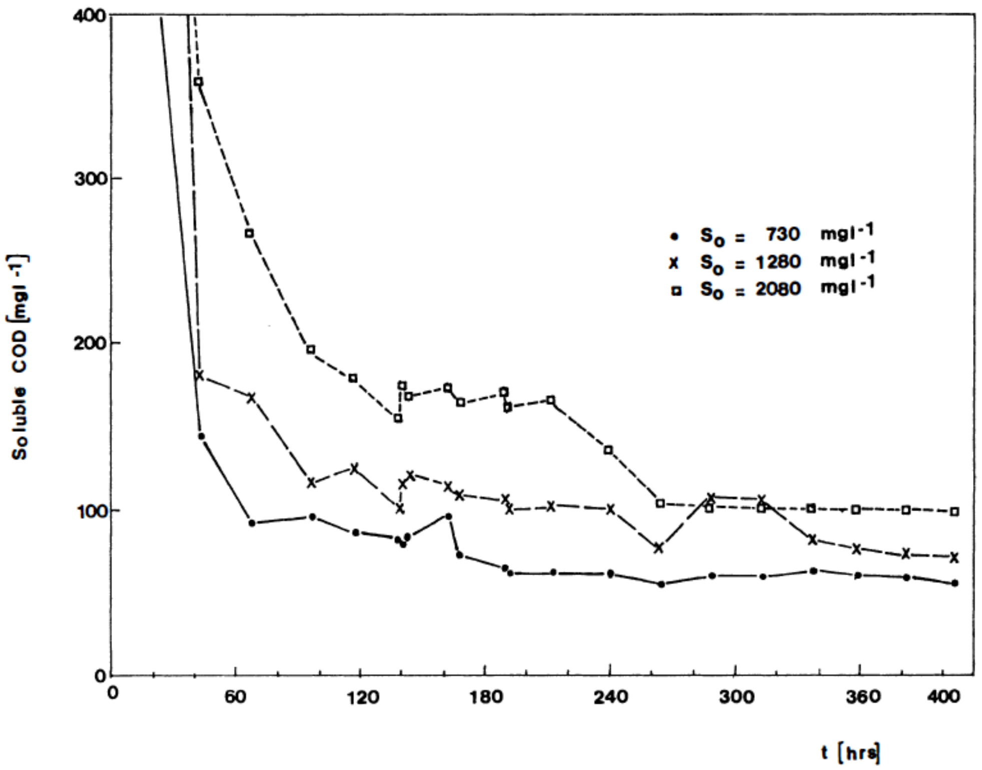


Fig. 1. Pulp and paper COD profiles

pH and precipitation reactions

- Detailed physio-chemical model needed for accurate pH-predictions
  => Important for struvite recovery model
- Measurements of ions in the wastewater

Parameter	Unit	Influent WWTP	Effluent WWTP	Industry
Calcium (dissolved)	mg Ca/L	x		x
Magnesium (dissolved)	mg Mg/L	x		x
Potassium (dissolved)	mg K/L	x		x
Sulphate (dissolved)	mg SO_4/L	x		x
Sulphide (dissolved)	mg S^{2-}/L	x		x
Inorganic carbon (TIC)	mg TIC/L	x		x
Strong cations (eg Na^+)	mg/L	x		x
Strong anions (eg Cl^-)	mg/L	x		x

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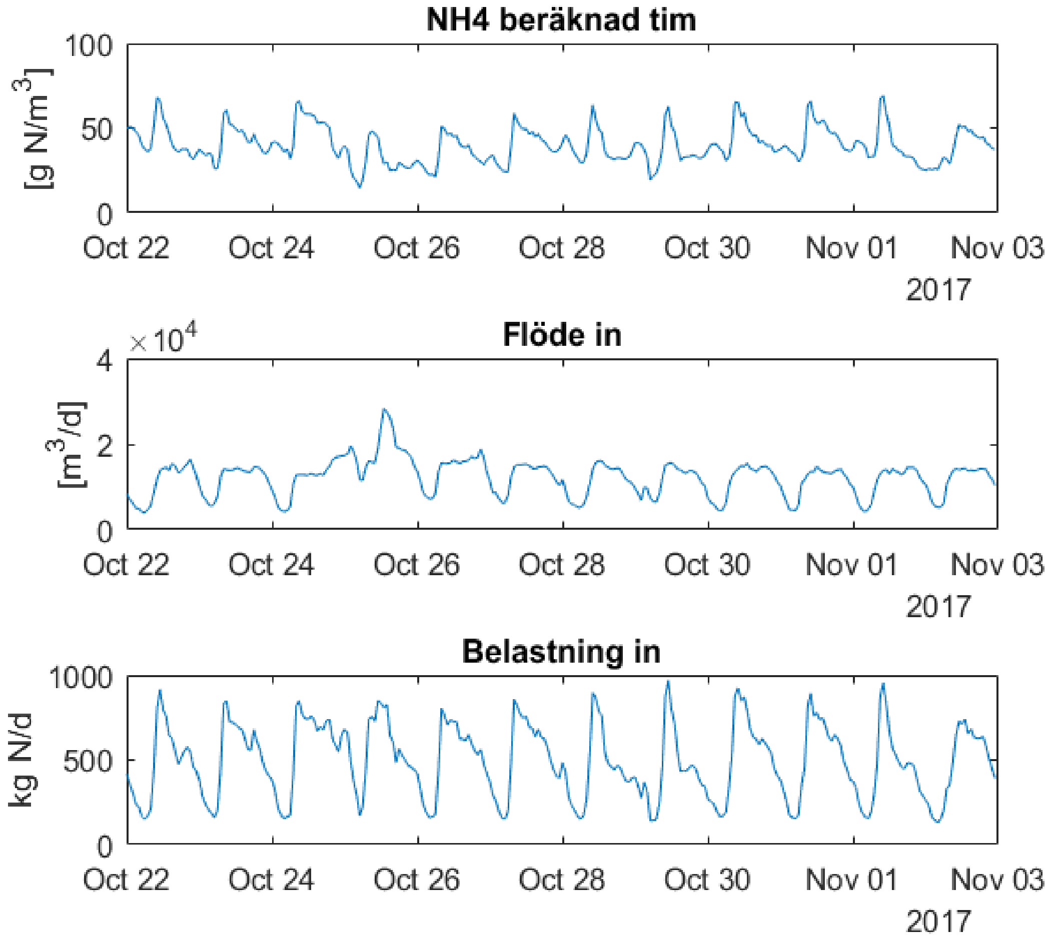
Dynamic input data

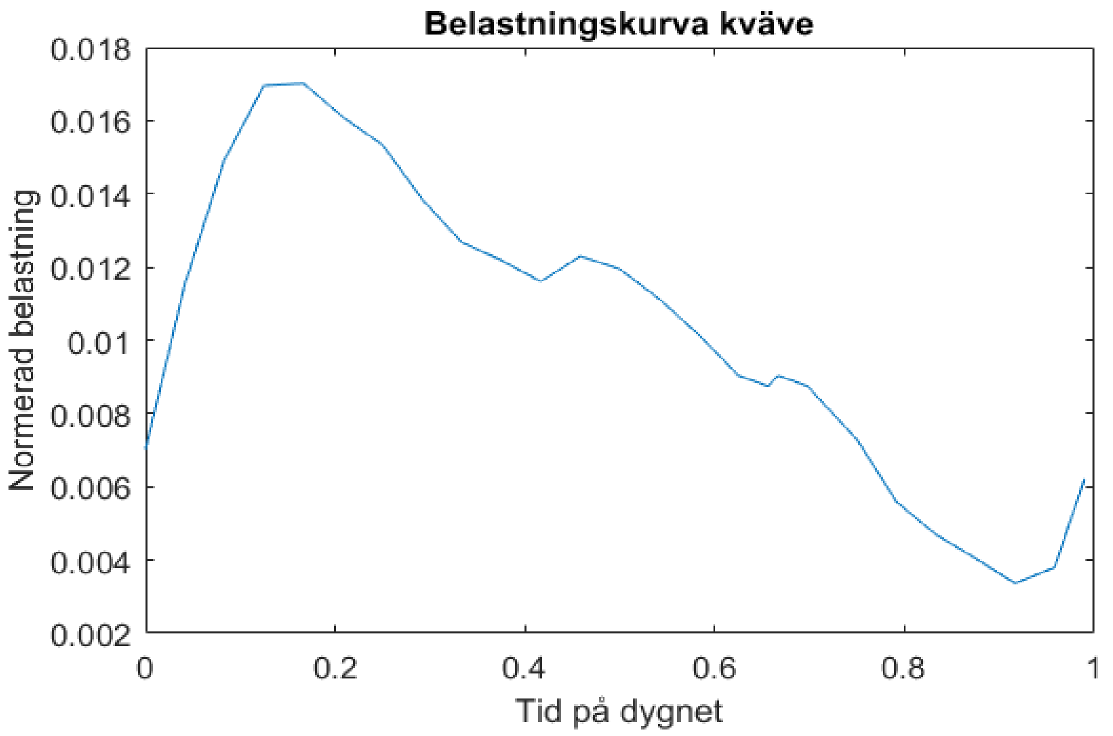
Dynamic input data

- Measurements over several days with high resolution (1 h average)
- Less detailed number of analyses:
  - COD_{tot}
  - COD_{filt}
  - N_{tot}
  - NH_4-N
  - P_{tot}
  - PO_4-P
  - TSS
  - VSS



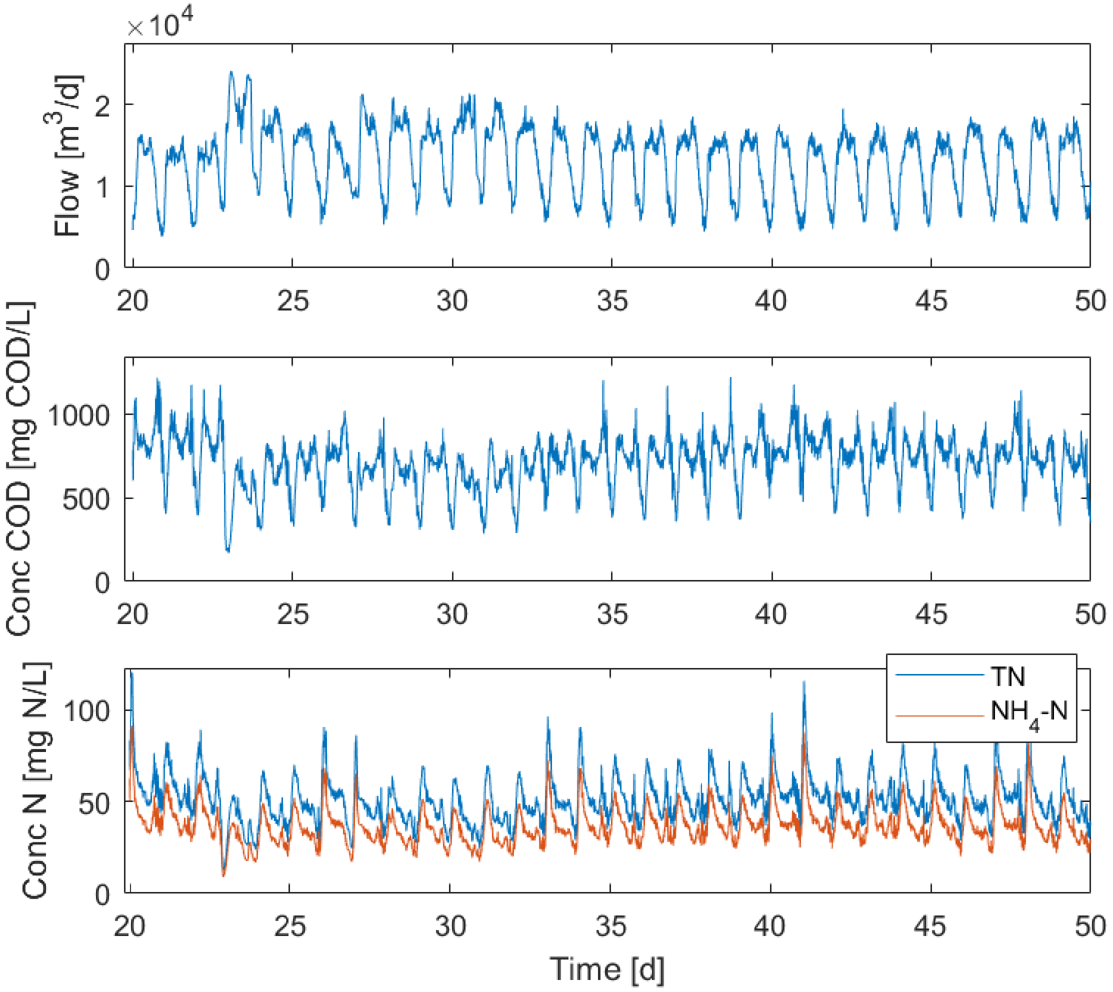
Dynamic input data

- Generalized diurnal load pattern for each pollutant
- Assumed identical for new WWTP
- Load multiplied with load distribution curve to obtain daily load variations



Dynamic input data

- Load divided by flow to obtain concentration
- New time series data are constructed



Literature review

Literature review

- Common intervals for wastewater characterization
- Common intervals for uncertain biokinetic parameters

Table 4 COD fractions relative to the $COD_{inf,tot}$ for the examined WWTPs

Ratio to $COD_{inf,tot}$	Min. – Average – Max.
S_I	0.03 – 0.06 – 0.10
S_S	0.09 – 0.26 – 0.42
X_S	0.10 – 0.28 – 0.48
X_I	0.23 – 0.39 – 0.50
BCOD	0.45 – 0.55 – 0.68
BZV_5	0.32 – 0.40 – 0.51
$COD_{inf,part}$	0.47 – 0.68 – 0.88

Literature review

- Ozonation impact on fractions

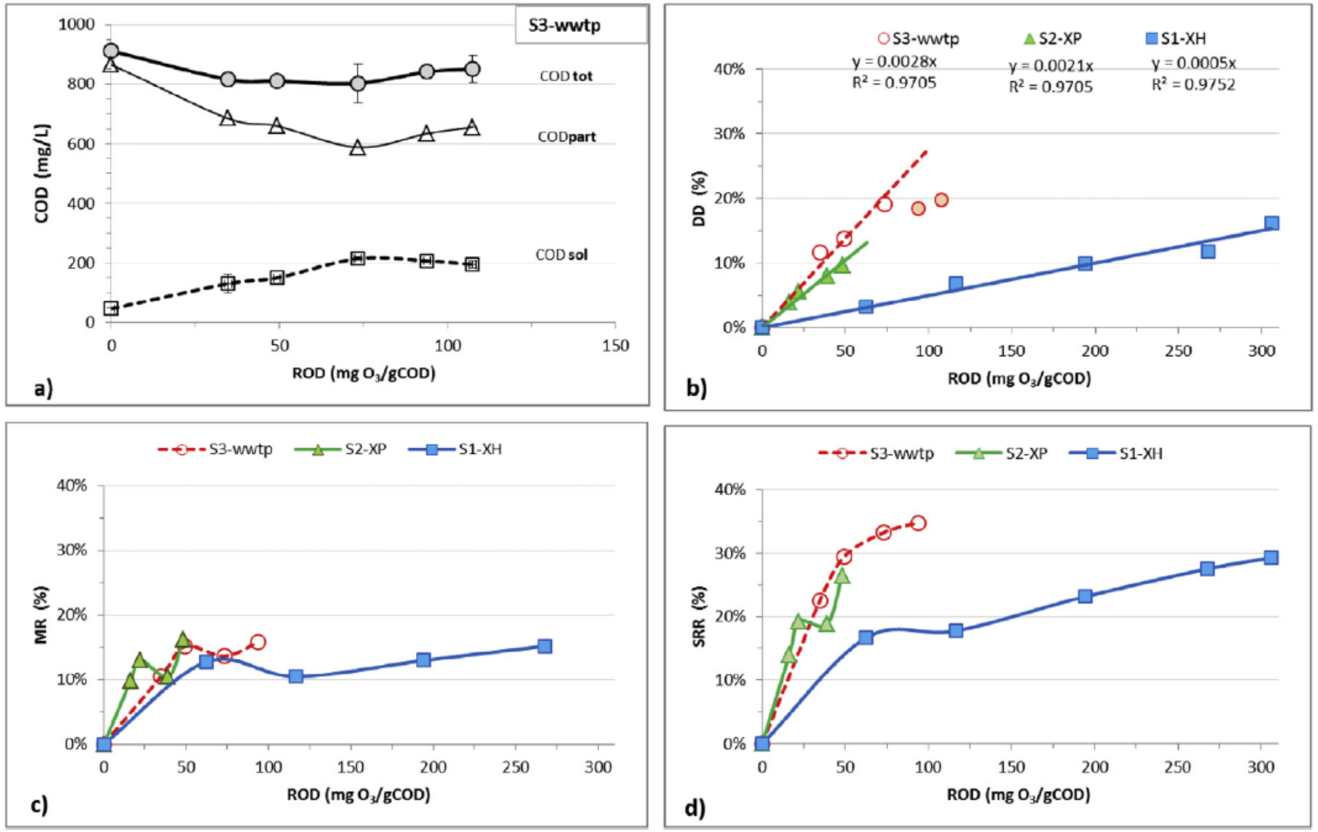
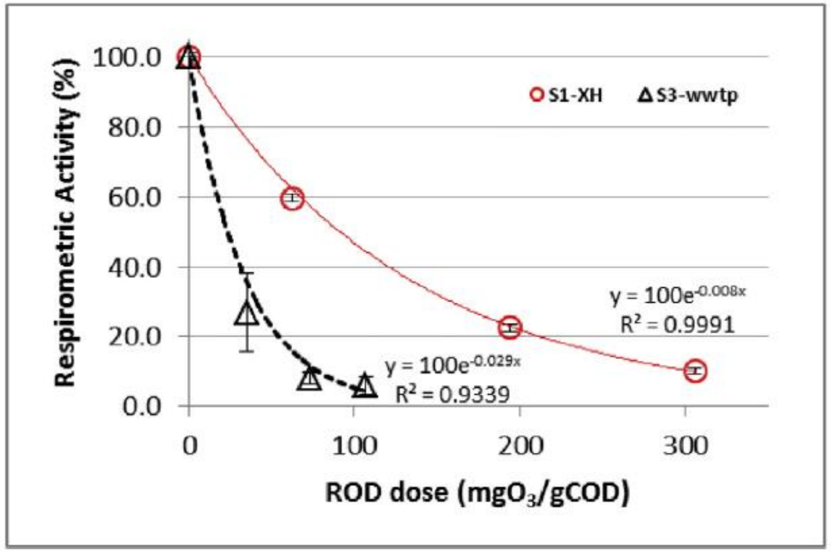


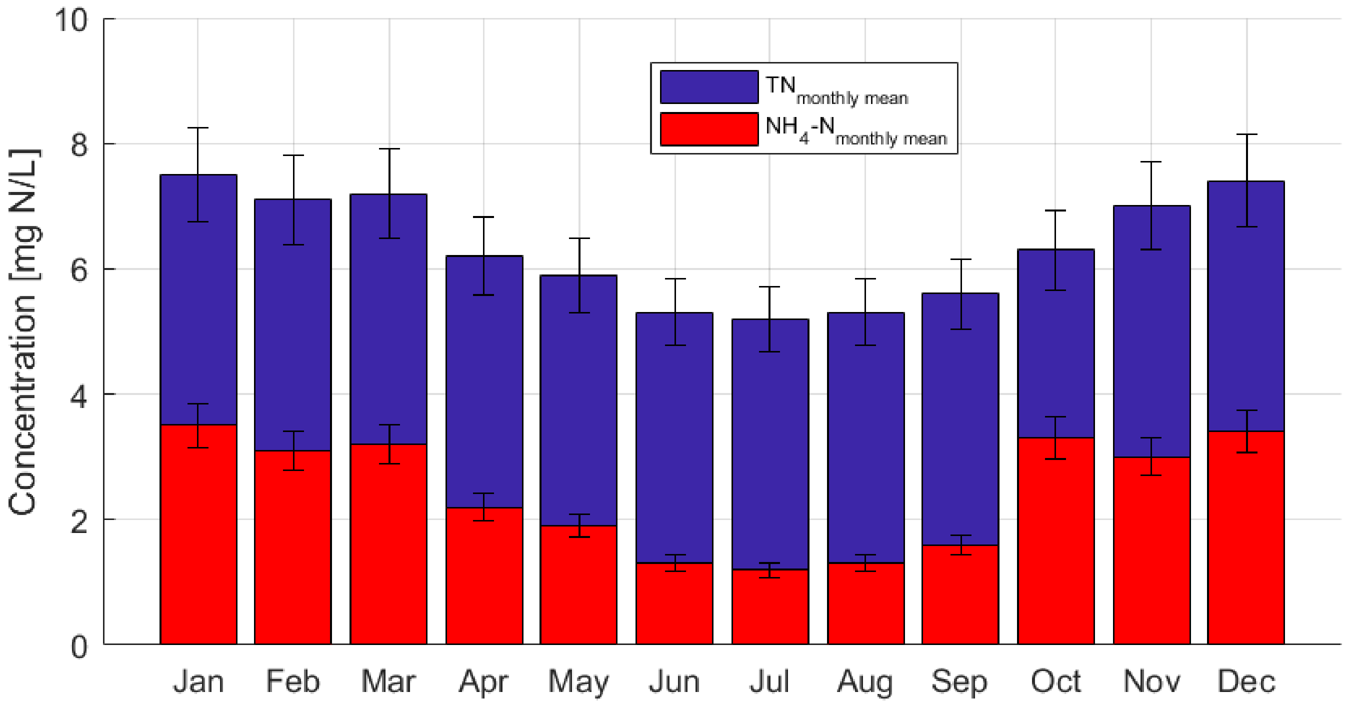
Fig. 5. Ozone effects on the solids: a) COD conc. trends, b) dissolution degree - DD, c) mineralization ratio - MR, d) and total sludge reduction ratio - SSR.



Sensitivity analysis

Sensitivity analysis

- Vary uncertain parameters
  - Biological parameters
  - Wastewater characterization
- Quantification of uncertainty



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