CALIBRATION AND VALIDATION OF WASTEWATER TREATMENT PLANT MODELS

PÖYRY

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FIRST REFLECTIONS

- Models are approximations of reality
- Learn the one(s) you use: assumptions, shortcuts, math
- If you do not understand your model's mathematical structure and underlying assumptions, you cannot understand why it behaves like it does
- Models usually are less erroneous than your data
- Choose one or two standard models and learn to master them

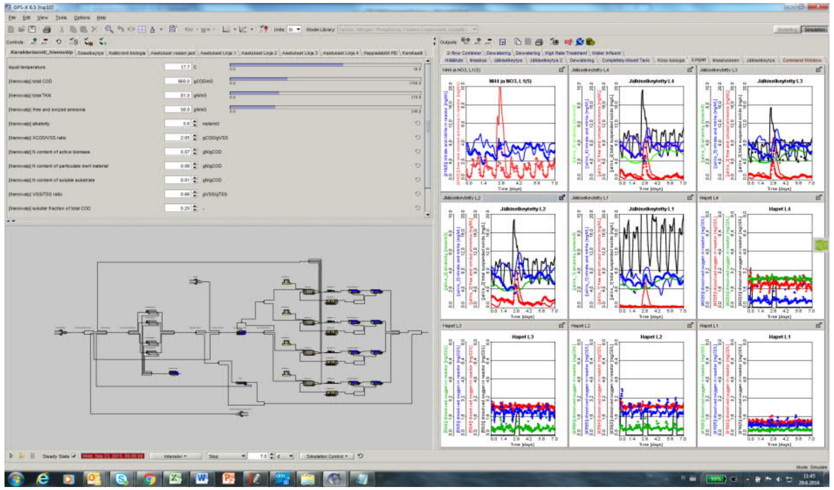
$$\mu = \mu_H \cdot \frac{S_{O2}}{K_{O2} + S_{O2}} \cdot \frac{S_{NH4}}{K_{NH4} + S_{NH4}} \cdot \frac{S_{ALK}}{K_{ALK} + S_{ALK}} \cdot \frac{X_{STO} / X_H}{K_{STO} + X_{STO} / X_H} \cdot X_H$$

MODEL CALIBRATION

- What?
  - – determine validity of structural assumptions
    - – hydraulic behaviour, flow division
    - – aeration
    - – control
  - – choose correct values for physical, chemical, biological etc. parameters of your model

- How?
  - – minimize error between simulation results and data measured from the modelled system

- Why?
  - – ensure reliable simulation results
  - – verify your model



CALIBRATION APPROACHES

- Process engineering approach
  - change parameters on the basis of reasoning and process expertise
  - usually used by process engineers, consultants, utilities
  - focus on parameters known to have a direct effect on certain process phenomena
    - b_N → nitrification
    - K_{O2} → floc-internal denitrification

- Systems engineering approach
  - use mathematical optimisation methods
  - usually used by researchers (e.g. for development of models on the basis of lab-scale processes)
  - usually models are not uniquely identifiable
    - E.g. ASM2D has 14 state variables and ~40 biokinetic parameters

- Combination of the two
  - check sensitivity of the model towards parametres changed through process engineering approach

CALIBRATION PROTOCOLS

- WERF (USA, Australia)
- BioMath (Belgium)
- STOWA (Netherlands)
- HSG (Austria, Germany)

- Instruction sets on calibration procedures, data gathering & processing etc.
- Process engineering approach, aimed for practitioners

GENERIC CALIBRATION PROCEDURE

- Setting project objectives
- System definition and model structure
- Data collection
- Data quality and analysis
- Wastewater characterization
- Preparing input data sets
- Calibration
- Validation

SETTING PROJECT OBJECTIVES

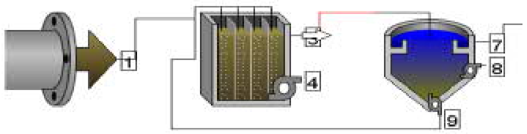
- THE MOST IMPORTANT PART OF MODEL CALIBRATION
  - Happens before the model exists
- Objectives define the required model structure, complexity and data
- Common objectives (in order of complexity)
  - Training / demo
  - Comparative studies, scenarios
  - Process dimensioning
  - Operational strategies
  - Control design and optimisation

SYSTEM DEFINITION AND MODEL STRUCTURE

- Plant flow scheme
  – What units to be modelled?
  – One treatment train vs. all trains?
  – Hydraulic considerations
  – Feeding points of wastewater, sludge and chemicals to process tanks

- Aeration
  – Diffuser type and setup

- Operation and control



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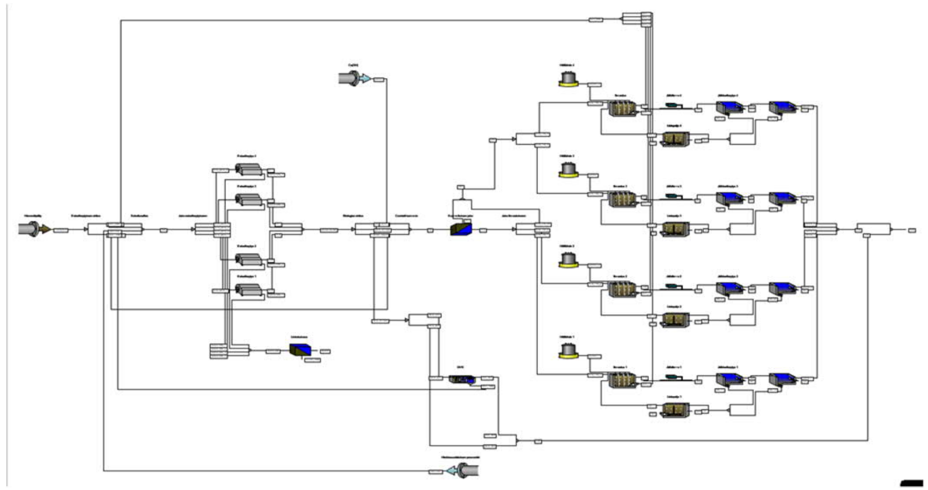
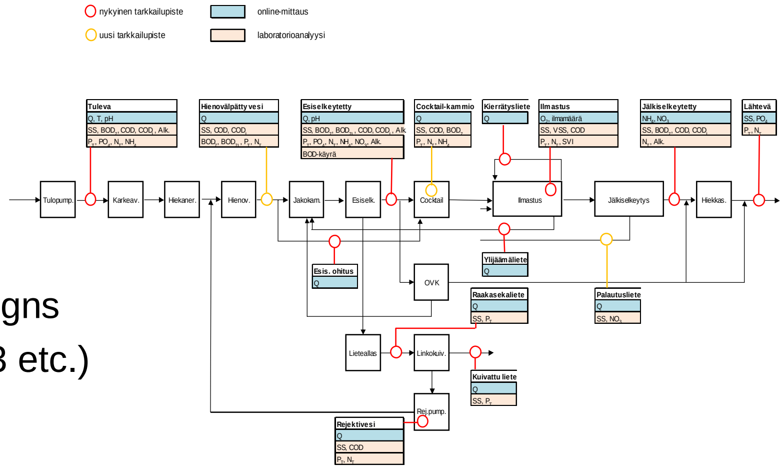


?

DATA COLLECTION

- Defaults and assumptions
  - Very rough “calibration”
  - For greenfield sites (the plant does not yet exist)

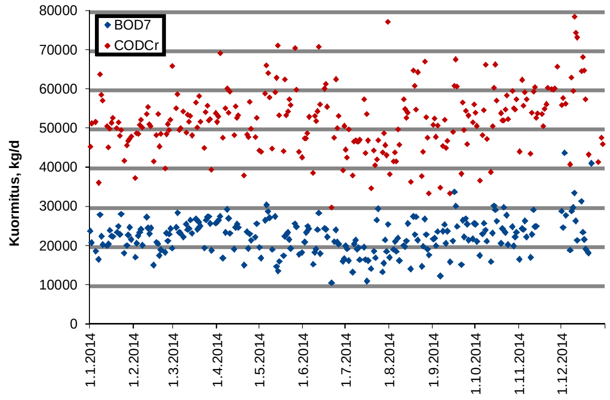
- Historical plant data
  - Crude calibration
  - Necessary information usually missing: COD fractions, diurnal variation, sludge blanket…



- On-site measuring programs, full-scale tests
  - Sampling and analysis program 3 – 14 d
  - 24 h composite samples
  - Online measurement data, 2h grab sampling campaigns
  - Additional analyses (influent VFA, return sludge NO3 etc.)

- Direct parameter measurements (lab, batch tests)
  - OUR
  - Nitrification rates

DATA QUALITY AND ANALYSIS



- Garbage in = garbage out
- Data always contains errors
- Check
  - Sampling locations, mixing conditions, devices
  - Sampling procedures, sample preservation and processing
  - Averages and outliers
  - Operational status, e.g. maintenance procedures during data collection
  - Calibration of online measurements and analysers
  - Flow measurements, especially excess sludge wastage rate

- Methods
  - Statistical methods
  - Strong checks (law of nature):
    - Flow balances, inert mass balances (P, Fe)
  - Engineering checks (typical behaviour)
    - Traditional design guidelines
    - Typical ratios and yields

DATA QUALITY AND ANALYSIS

Esiselkeytetty		
Virtaama	89663	m3/d
BOD	14599	kg/d
COD	32859	kg/d
SS	12922	kg/d
Nkok	4768	kg/d
Pkok	382	kg/d

Kalkki		
Annostus	2951	kg/d
Annostus	36	g/m3

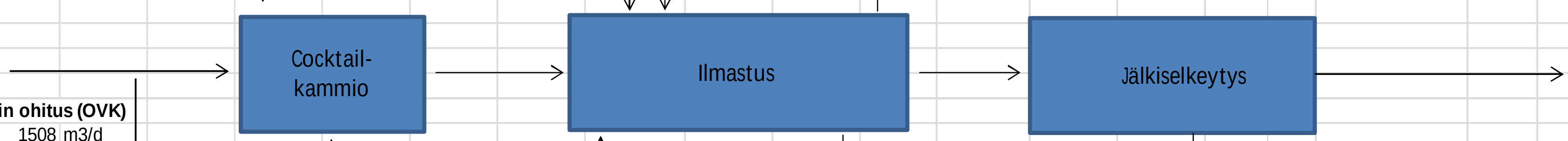
Ilmastukseen (Cocktail)		
Virtaama	98760	m3/d
BOD	13909	kg/d
COD	34155	kg/d
SS	15390	kg/d
Nkok	5226	kg/d
Pkok	407	kg/d

Metanoli 10 %		
Annostus	2,6	m3/d
		kgTS/d

Kierrätysliete		
Virtaama	239213	m3/d

Ferrosulfaatti 2		
Virtaama	6	m3/d
Annostus	24	g/m3
	2330	kg/d
	769	kgTS/d

Jälkiselkeytetty		
Virtaama	88151	m3/d
BOD	481	kg/d
COD	4125	kg/d
SS	940	kg/d
Nkok	1208	kg/d
Pkok	25	kg/d



Biol. prosessin ohitus (OVK)		
Virtaama	1508	m3/d
SS	217	kg/d
Pkok	6	kg/d
BOD	246	kg/d

Esiselkeytyksen ohitus		
Virtaama	11792	m3/d
SS	4557	kg/d
Pkok	89	kg/d
BOD	3399	kg/d

Palautusliete		
Virtaama	118219	m3/d
SS	557354	kg/d
NO3-N	1010	kg/d

Ylijäämäliete		
Virtaama	4026	m3/d
SS	16405	kg/d
VSS	11190	kg/d
Nkok	1091	kg/d
Pkok	417	kg/d

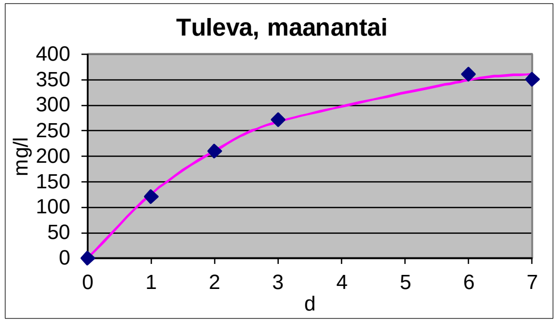
Tase, cocktail-kammio			
	in-out		Virhe: (in-out)/in
Q	1187	m³/d	1,3 %
Kok-P	58	kg/d	16 %
SS	1872	kg/d	11 %

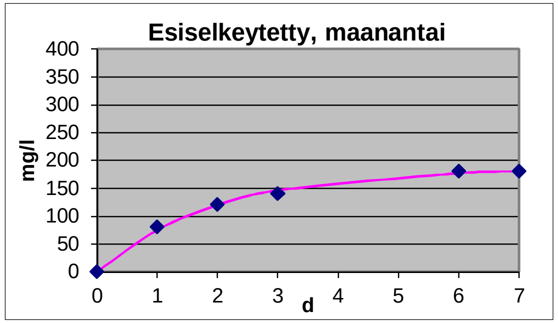
Tase, ilmastus + jälkiselkeytys			
	in-out		Virhe: (in-out)/in
Q	6592	m³/d	6,7 %
Kok-P	29	kg/d	6,3 %
SS	695	kg/d	4,5 %

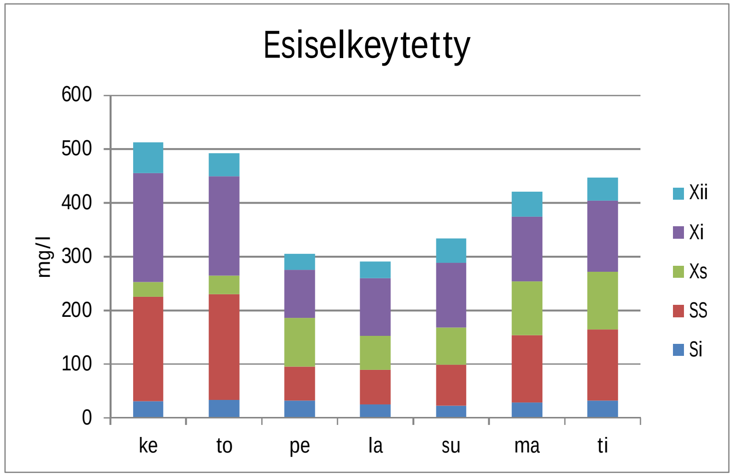
Laskennassa käytetty esiselkeytetyn ja hienovälpätyn analyysituloksia

WASTEWATER CHARACTERISATION

- Organic carbon fractions (COD)
  - readily biodegradable, slowly biodegradable, inert
  - BOD curve, OUR, VFA, soluble vs total COD & BOD
- Nutrient fractions
  - NH4, NO3, Ntot, PO4, Ptot
- SS, VSS, alkalinity

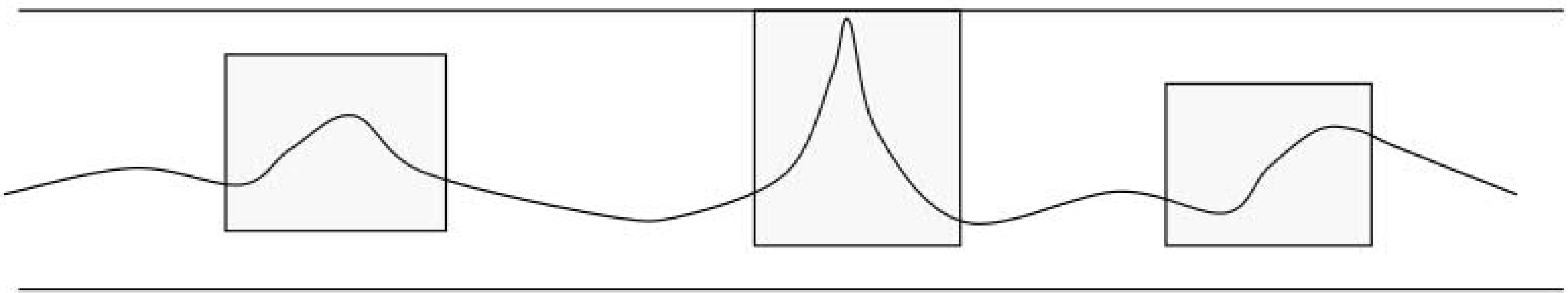






PREPARING OF INPUT DATA SETS

- Filter data
- Make clean steady-states (winter, summer…) during which sludge retention time is approximately constant → steady state simulation
- Select periods with large dynamics (process upsets, heavy rains, snowmelt, operational changes) → dynamic simulation
- Finally run with the whole dataset



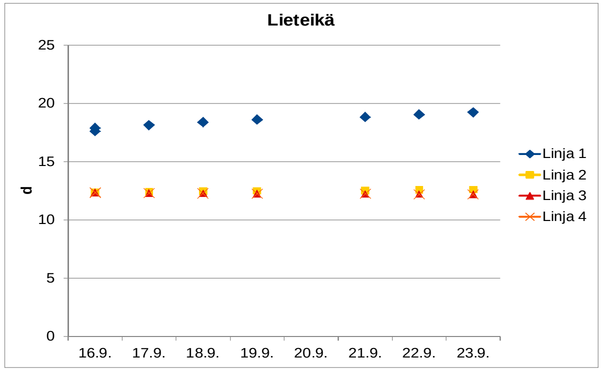
FIRST SIMULATION AND ORDER OF CALIBRATION

- Calibrate **biological processes** in the following order:
  - Sludge production → MLSS, MLVSS
  - Nitrogen removal → assimilation, nitrification, denitrification
  - Phosphorus removal → biological, chemical

- Change **parameters** in the following order:
  - System definition and model structure
  - Influent characterisation
  - Kinetic and stoichiometric parameters

- In full-scale projects, system definition, model structure, data quality and influent characterisation make up to 90 % of calibration
  - Example: feeding point of sludge to settler vs. Vesilind coefficients
  - In well-defined lab scale processes, model parameters are more important

CALIBRATION: SYSTEM DEFINITION AND MODEL STRUCTURE



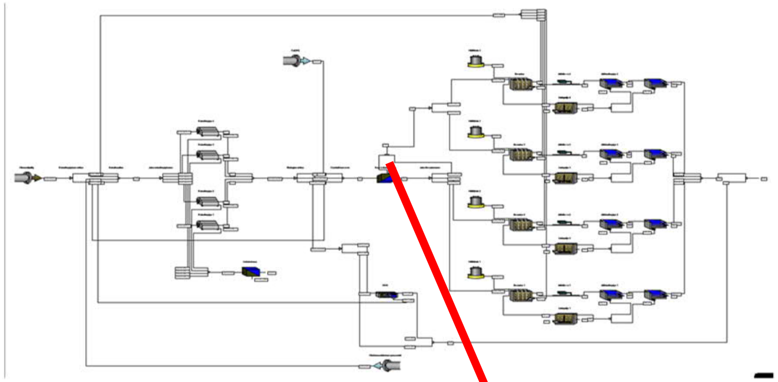
- Are all trains really identical?
  - Year of construction, historical changes
  - True dimensions vs drawings
  - Operation strategies

- Is flow and load division modelled correctly?
  - Distribution chambers and channels
  - Backflow in aeration zones → true anoxic and anaerobic volumes
  - Sludge feed level to secondary sedimentation

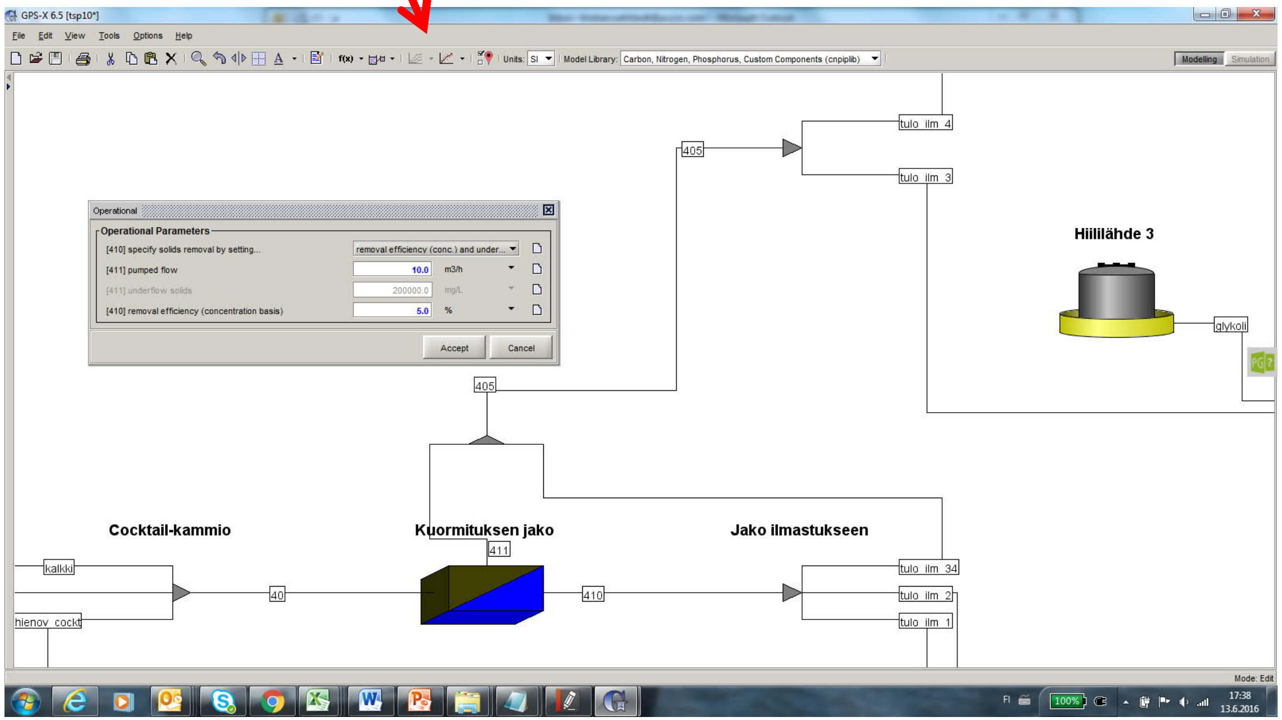
- Are all relevant functions included and modelled correctly?
  - Properties and dilution of process chemicals

- Is sludge retention time correct?
  - Extraction point of excess sludge
  - Volume removed
  - MLSS concentration in excess sludge

CASE EXAMPLE: SYSTEM DEFINITION AND MODEL STRUCTURE

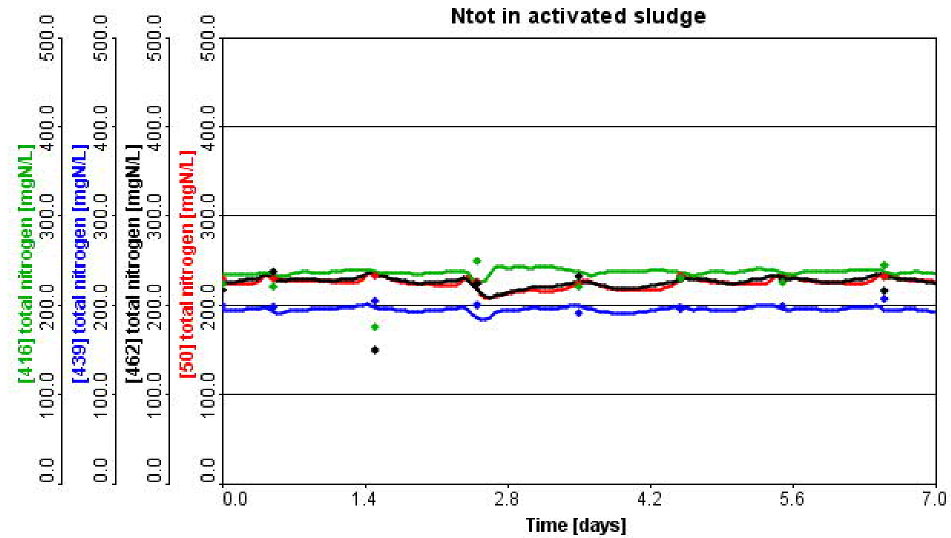


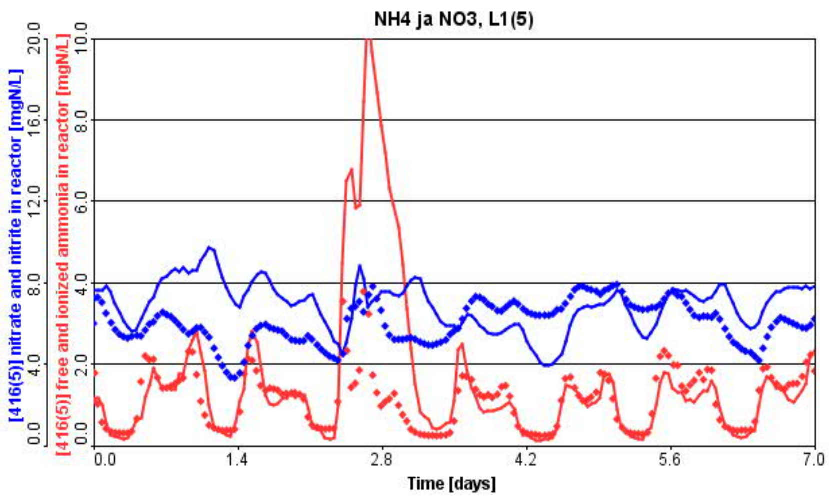
- Uneven division of organic and solids load to aeration lines at the Turku Kakolanmäki WWTP
- “Virtual separation” of 10 % of X-concentrations before division point → feed to more heavily loaded lines



CALIBRATION: INFLUENT CHARACTERISATION

- Sludge production:
  - X_I / XCOD
  - COD/VSS
  - VSS/TSS
- Nitrification
  - S_{ALK}
  - $i_{N,X}$
- Denitrification
  - S_S / SCOD
- Biological phosphorus removal
  - SF (SS, SA)





CALIBRATION: MODEL PARAMETERS

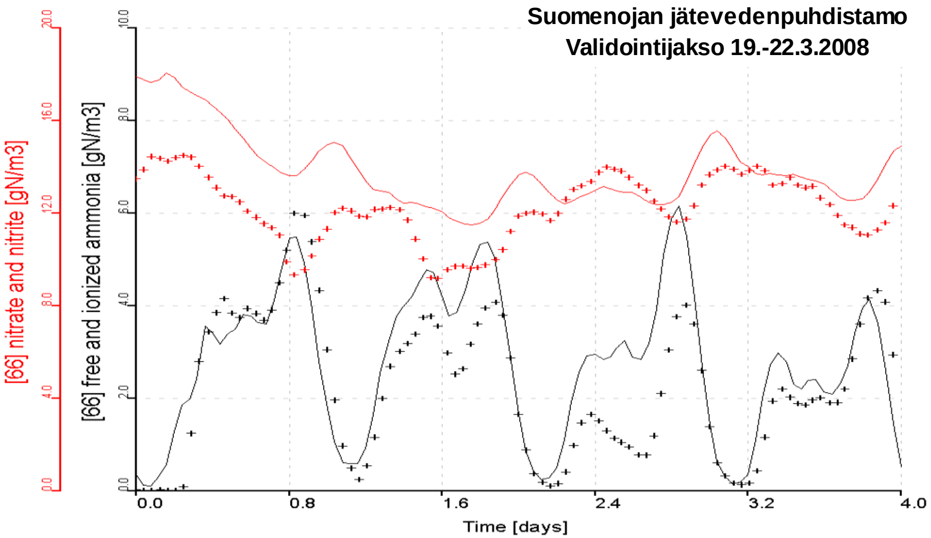
- No one and only correct philosophy
- In general, use parameters which
  - Have a wide range, are not well known/established
  - Have a direct impact on the process you are calibrating
  - Have an impact which can be reasonably explained and connected to real situation at the plant
- Use batch tests and curve fitting, if possible
- Develop your own philosophy and learn how it works
- Typical calibration parameters
  - f_{XI} → sludge production
  - $i_{N,X}$ → nitrogen content of sludge, nitrogen removal
  - bA → nitrification
  - η_{NO}, K_{O2} → denitrification
  - q_{Fe} → biological phosphorus removal

VALIDATION

- Validate your model (if you dare) to improve its applicability and reliability

- Use preferably two data sets
  - independent of each other and of calibration data
  - Collected at least one SRT from each other
  - Different temperature and flow conditions, process operational settings

- Do not change any model parameters



FINAL REFLECTIONS (1)

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- Learn the one(s) you use: assumptions, shortcuts, math
- If you do not understand your model's mathematical structure and underlying assumptions, you cannot understand why it behaves as it does
- Models usually are less erroneous than your data
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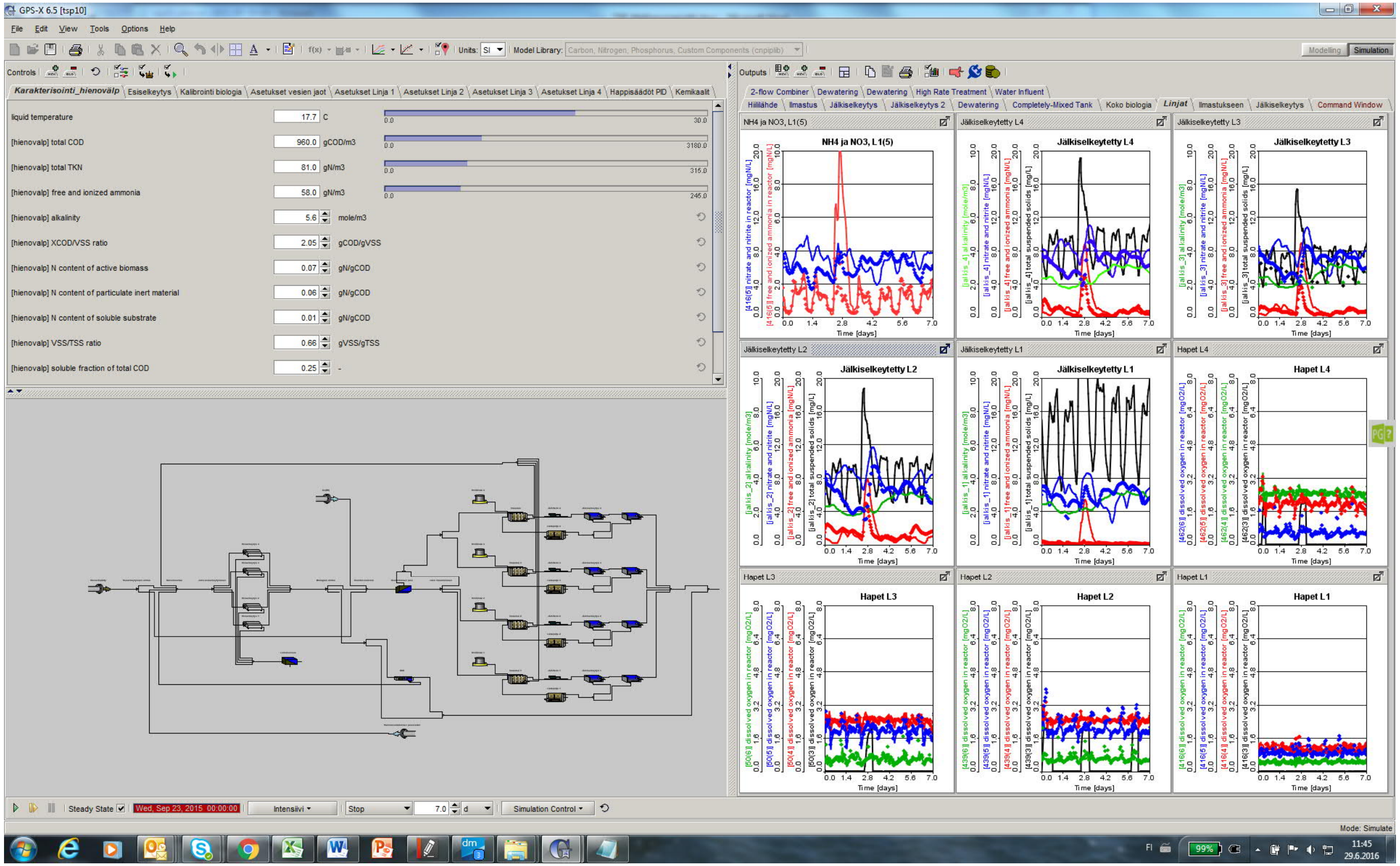
FINAL REFLECTIONS (2)

- Three golden rules (Jeppsson)
  - Do not fall in love with your model
  - Do not try to adapt reality into your model
  - Do not push the limits of validity of your model too far

- DOSE rules for the practitioner
  - Data: amount and quality
  - Objectives: set them and stick with them
  - Structure: get it right – 10 times more important than reaction rates
  - Excellence: know what you are doing

THANK YOU!



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