DATA EVALUATION

Evaluation of input and reference data for activated sludge models

Stefan WINKLER Vienna University of Technology

OVERVIEW

- Methods for evaluation of (WWTP routine operation) data for AS-models

- Overview on possible error sources

- Planning and preparation of special monitoring campaigns for acquisition of additional (non-WWTP routine operation) data

- Evaluation of results from special monitoring campaign ⇨ Correction/improvement of initial data evaluation results ⇨ Determination of residual error assignment

- Application of evaluated WWTP-data set for AS-modelling

DATA EVALUATION
Methods

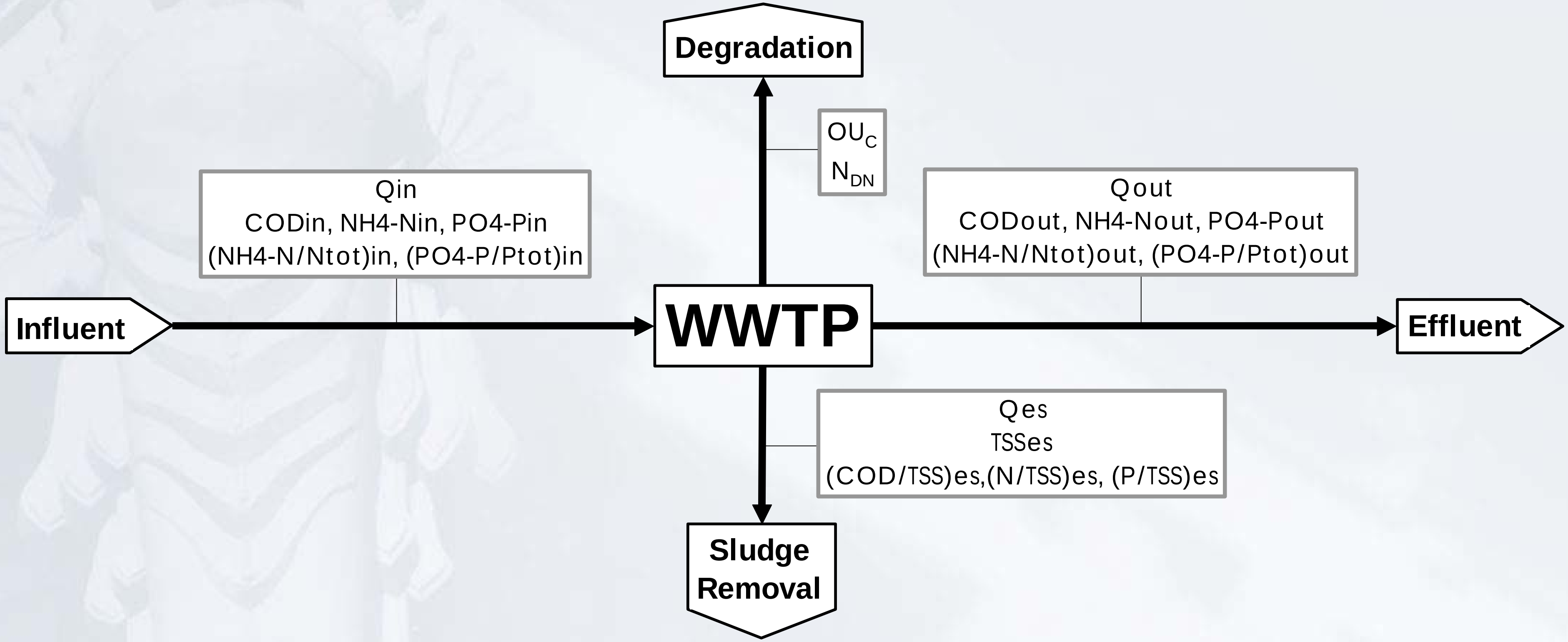
- **Theoretical based methods**
  - ***Evaluation of applied measurement methods based on theoretical knowledge, technical standards, literature values***

- **Experimental based methods**
  - ***Mass balances***
  - ***Reference measurements (alternative measurement principle)***
  - ***Quantitative control (dilution and recovery experiments, etc.)***

⇨ ***Goal: To create an evaluated (and reconciled) data set which describes the main plant characteristics for the investigated scenario(s). This data set is used as the base for model calibration.***

DATA EVALUATION

Mass balances: General format



Parameters: COD, N, P, Q, (Fe)

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Mass balances: General remarks

- *Quasi steady state: MLSS, temperature, plant loading (mobile sludge dewatering at smaller plants), plant operation, 2 – 3 * SRT; storage*
- *'Open' and 'closed' mass balances*
- *OU_C can – in principle – be measured with respirometric tests*
  - ⇨ *Temperature control of the respirometric vessel*
  - ⇨ *F:M – ratio representative for average loading conditions of mass balance period*
  - ⇨ *V_D:V – ratio has to be considered for interpretation of results*
  - ⇨ *Other respirometric tests: Maximum actual nitrification rate (Nowak et al., 1994)*
- *TSS_{EFF} – load can be included in excess sludge withdrawal; stripping can be included in degradation*

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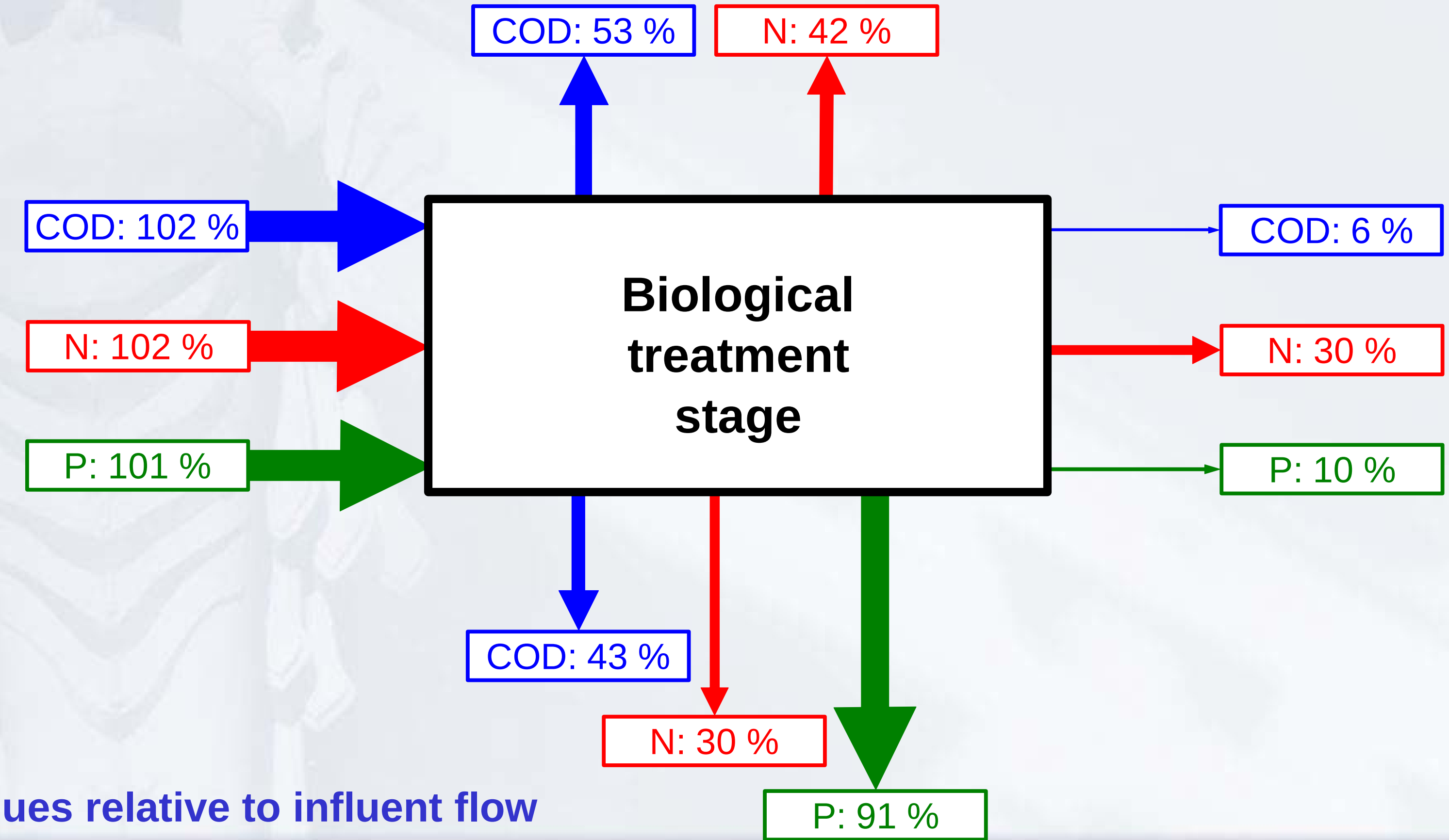
Mass balances: Basic systems (1)

Activated sludge plant with simultaneous sludge stabilisation



All values relative to influent flow

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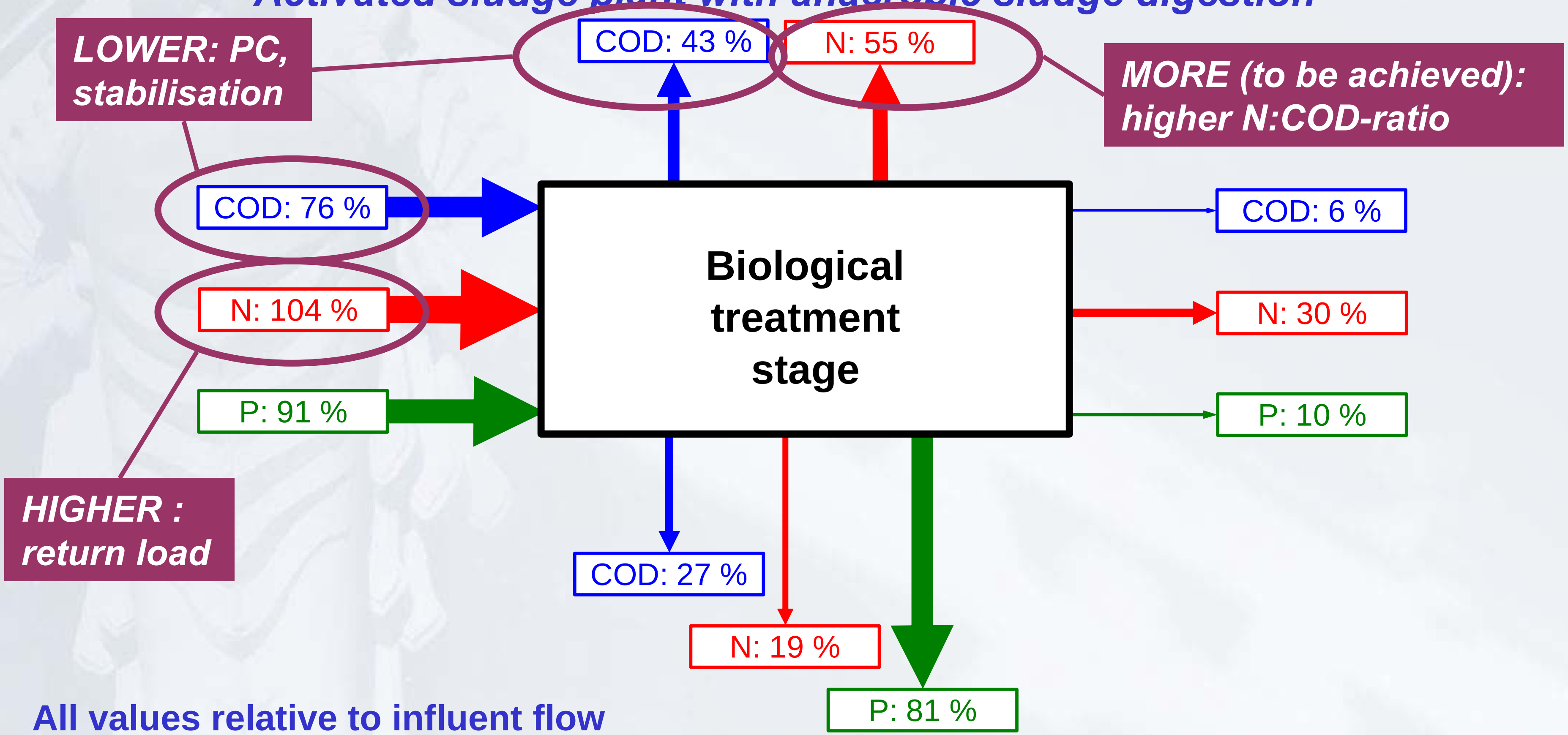
Mass balances: Basic systems (2)

Activated sludge plant with anaerobic sludge digestion



All values relative to influent flow

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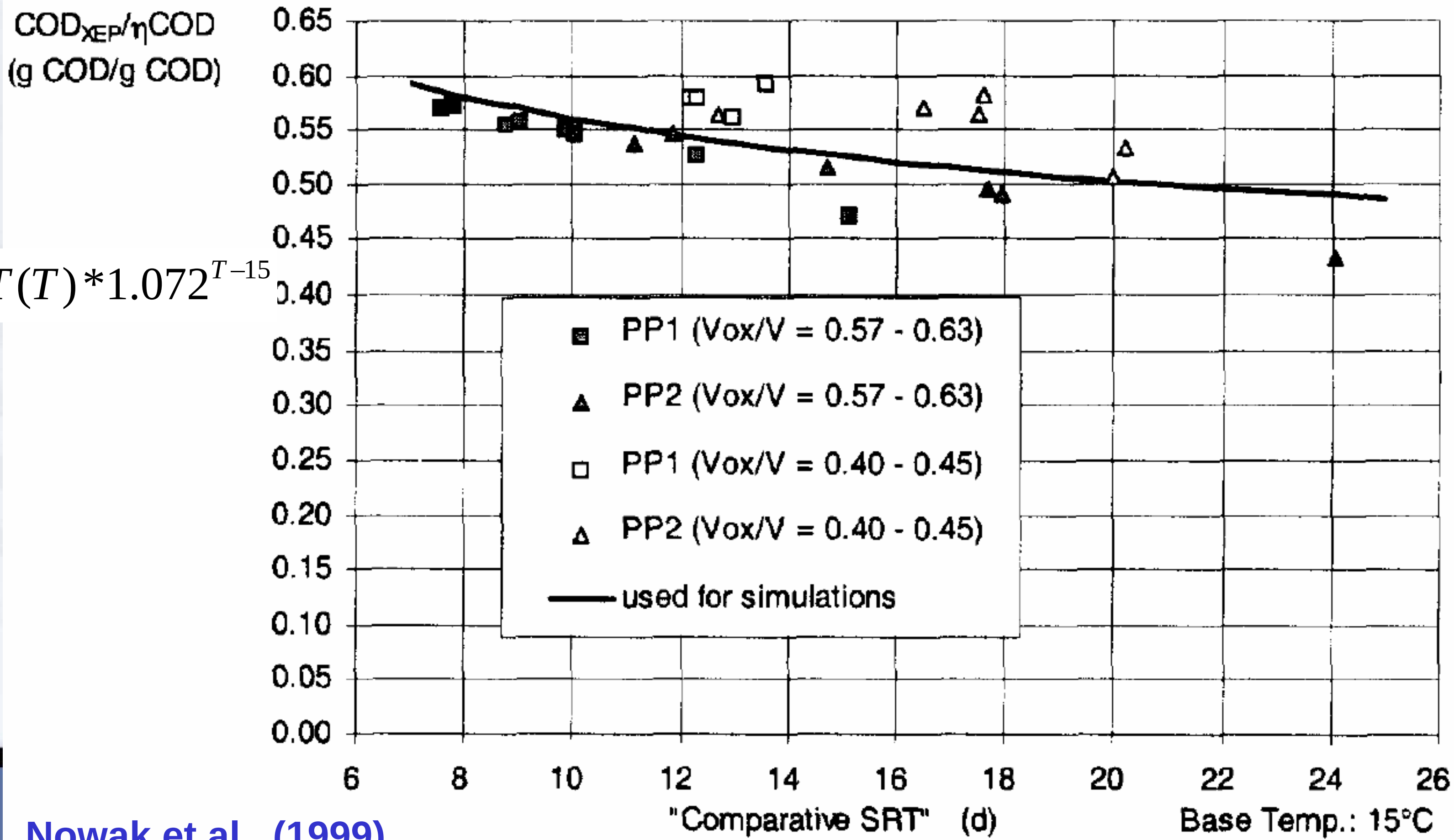
Mass balances: Sludge production and oxygen consumption

'Comparative' SRT at T = 15 °C – SRT_{15} (Nowak et al., 1999):

$$SRT_{15} = SRT(T) * 1.072^{T-15}$$



Nowak et al., (1999)

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Mass balances: Data reconciliation

Conclusions from initial mass balance set up

- *Check of results against 'benchmark' values*
- *Balance gaps or unrealistic results indicate need for further investigation*

⇨ ***Goal: To identify the main sources of data inconsistency in order to limit the required effort for further investigations and additional monitoring***

⇨ **Advanced methods**

- ***Meijer (2004) based on van der Heijden et al. (1994):***
Matrix formulation of mass balances, balance residuals ε_n are detected and later eliminated by balancing the system based on testing of error significance (κ^2-Test) and user defined settings
- ***Thomann (2002): Determination of cumulative frequency distribution (Monte-Carlo simulation) of balance residuum considering uncertainty of input data***

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Practical application

- **Basic considerations**
  - *Process flow diagram*
  - *Load in relation to population (and industrial discharge)*
  - *Typical ratio-values of COD, N, P and VSS (TSS) in wastewater and sludge (and per PE)*
- **Data evaluation - procedure**
  1. *Mass balance(s)*
  2. *Investigation of plant specific situation*
     - ⇨ *Flow measurement systems*
     - ⇨ *Sampling locations and methods*
     - ⇨ *Laboratory methods*
  3. *'Measurement chain'*

⇨ ***Iterative procedure***

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Flow measurement systems: Venturi channels

- *Accuracy according to DIN 19559 (channel width > 0.3 m, field conditions)*

	Factory calibration	Location specific calibration
$Q < 0.1\ Q_{MAX}$	Not defined	Not defined
$0.1\ Q_{MAX} \leq Q < 0.3\ Q_{MAX}$	20 %	10 %
$0.3\ Q_{MAX} \leq Q < Q_{MAX}$	12 %	6 %

$Q_{MAX,WW} \geq 2 * Q_{MAX,DW}$
$Q_{MAX,DW} \approx Q_d / 14$

⇨ $Q_{d\_AVG} \approx 0.3 * Q_{MAX,WW}$

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Flow measurement systems: Electromagnetic flow meters

- *Accuracy according to manufacturer specifications (laboratory conditions)*
  - ⇨ *0.3 – 1 % for upper (lower) measurement range*
- *KREKEL u. DALLWIG (1998) (field conditions)*
  - ⇨ *6 – 10 % for upper (lower) measurement range*

⇨ ***Faulty flow measurement results can contribute significantly to the total error (mass balance)***

⇨ ***EFM: Installation, inhomogeneous medium (air bubbles)***
⇨ ***Venturi channel: 'over sizing', deposits, calibration***

⇨ ***Q – balance (internal recycle streams; Meijer et al. 2001)***

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Sampling locations and methods

- *Automatic sampler: Installation (Gradients, flow velocity, solids settling, suction hose emptying)*
- *Automatic sampler: Condition (Biofilm growth, solids settling)*
  – Cleaning, Maintenance
- *Automatic sampler: Configuration/operation (time/flow proportional, sampling volume, temperature control) – Representative sample*
- *Spot sampling: Representative sample (Medium homogeneity, transfer from sampling beaker into sample bottle/cuvette, immediate filtration, sample labelling)*

⇨ *Thomann (2002)*

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Laboratory methods: Cuvette tests (1)

Possible error sources (Thomann, 2002):

- *Cuvette test quality (production, storage)*
- *Quality of standards for spectrometer calibration*
- *Photometer (calibration, optical system, cuvettes, air bubbles)*
- *Sample changes (immediate analysis, storage/cooling)*
- *Pipette errors (calibration, 'filtration', small volume)*
- *Analysis method (procedure, Min/Max, cross sensitivities: COD ↔ Cl)*
- *Data processing (unit, dilution rate, typing error)*

⇨ ***Pipette calibration, standard addition, spectrometer check and calibration, multiple (double) analysis, control cards***

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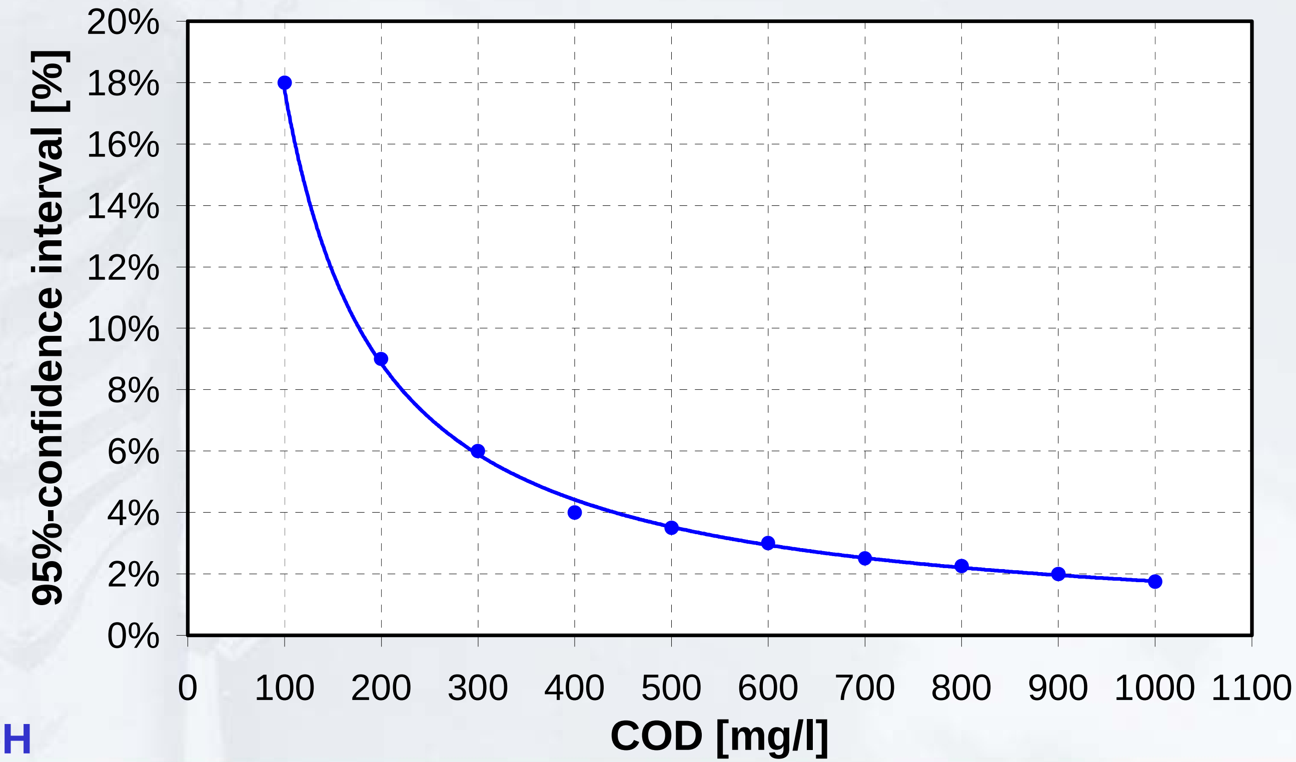
Laboratory methods: Cuvette tests (2)

- *Choice of suitable cuvette test*



LANGE GmbH

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Laboratory methods: Cuvette tests (3)

Coefficicient of variation CV [%] of cuvette tests						
	COD	P_{TOT}	N_{TOT}	NH_x-N	NO_3-N	PO_4-P
Aeration tank influent	2 – 7	2.5 – 6	2.5 – 3.5 (20)	4	5	4
WWTP effluent	16 – 37	2.5 – 10	1.5 – 7.5	1	2.5	6

Thomann (2002)

- ***ISO 15705 (2002): ST-COD (small scale sealed tube method)***

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Laboratory sludge analysis

- *Uncertainty of laboratory analysis results (sludge)*

$$N_{ES} = TSS_{ES\_WWTP} * \left(\frac{VSS * (1 \pm f_{VSS})}{TSS * (1 \pm f_{TSS})} \right)_{ES\_Lab} * \left(\frac{N * (1 \pm f_{N})}{VSS * (1 \pm f_{VSS})} \right)_{ES\_Lab}$$

- ***Precision: Total solids dried at 103 – 105 °C:***
  ‚Single laboratory duplicate analysis of 41 samples of water and wastewater were made with a standard deviation of differences of 6.0 mg/l‘

(Standard methods 2540 B, 1995)

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Basic checks of on-line measurement systems

- 'Measurement chain'
  - *Sensor: Installation (Gradients, flow velocity)*
  - *Sensor: Condition – Cleaning, Maintenance*
  - *Sensor: Reference measurement – Min/Max – check, Calibration*
  - *Data transfer: Reading on local display vs. WWTP control room*
  - *Data processing: Actual vs. processed value (automatic aggregation)*

⇨ ***Continuous monitoring with control charts (Thomann et al. 2001)***

⇨ ***Rieger (2004)***

ADDITIONAL MONITORING

Preparation and planning

- *Only after previous evaluation steps indicate the need for additional measurements and/or dynamic data is required*
- *Communication with WWTP personnel (steady state, planned revision work)*
- *Checking laboratory procedures and on-line measurement equipment*
- *Determination of additional measurements*
  - ⇨ *What, where, how, who, frequency*
  - ⇨ *Sludge analysis: TSS, VSS, COD, N, P*
  - ⇨ *Effluent solids (low accuracy: 10 mg/l ± 30%, Thomann, 2002)*
    - ⇨ *± 1 - 2 % of ES-production*
  - ⇨ *Energy consumption (aeration)*
  - ⇨ *Influent dynamics*
  - ⇨ *Tracer tests*

ADDITIONAL MONITORING

Example (1)

- **Excess sludge production – SRT**
  - ***P-balance WWTP***

$$Q*\left(P_{TOT,IN}-P_{TOT,EFF}\right)+\Delta P-L_{AT}=Q_{ES}*TSS_{RS}*\left(\frac{VSS}{TSS}\right)_{RS}*\left(\frac{P_{TOT}}{VSS}\right)_{RS}$$

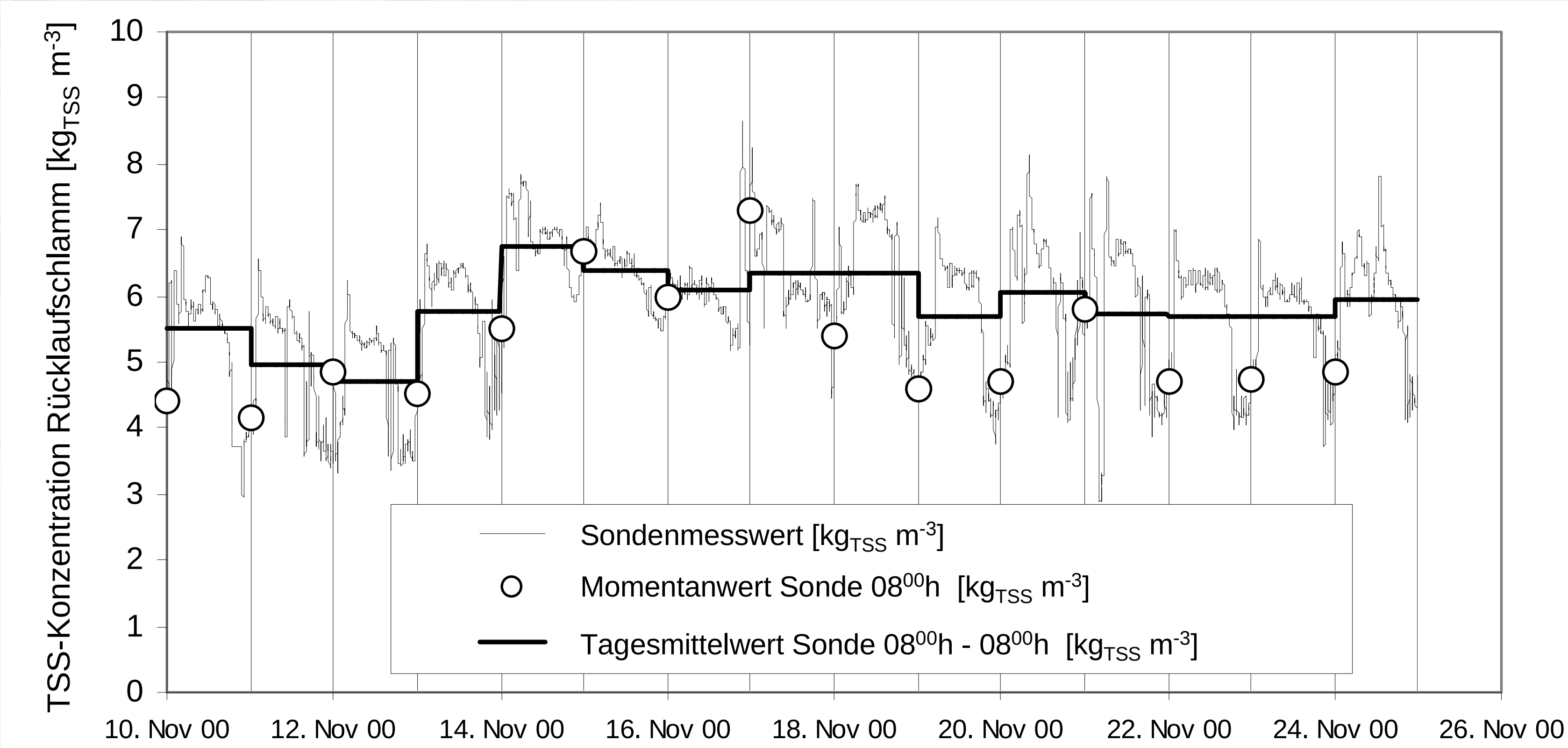
  - ***TSS-balance final clarification***

$$\left(Q+Q_{RS}\right)*MLSS-TSS_{RS}*\left(Q_{RS}+Q_{ES}\right)-Q*TSS_{EFF}=0$$

- ***Based on a measurement of 2 – 7 additional parameters a redundant check of the sludge production and subsequently the SRT can be carried out***
- ***The monitoring campaign needs to be sufficiently long (SRT)***
- ***Storage in the aeration tank has to be considered***
- ***Sludge production from phosphorous precipitation has to be considered in the model***

ADDITIONAL MONITORING

Example (2): TSS_{RS}-diurnal variation (Thomann, 2002)



Based on spot samples at 8:00 ⇨ TSS_{RS}-daily average underestimated by 15 %

ADDITIONAL MONITORING

Evaluation of results and data reconciliation

- **Recalculation of initial mass balances including additional (new) data**

- **Closing balance residuals based on user judgement**
  ⇨ ***Residual error is 'manually' assigned to certain flux paths***

DATA EVALUATION RESULTS

Application for model calibration

- **Model calibration is based on reconciled data set from data evaluation procedure**

- **Model calibration is to be performed as a stepwise procedure starting with calibrating the long-term behaviour of the system (excess sludge production, SRT)**

⇨ ***Winkler et al. (2001)***

- **Additional experiments (sludge stabilisation, respirometric tests) deliver valuable information for the model calibration procedure**

CONCLUSIONS

- Data evaluation and reconciliation is a mandatory procedure before model calibration is started
- Data evaluation is to be performed as a stepwise procedure, starting with basic plausibility checks and setup of initial mass balances
- Balancing residuals are starting point for further investigations
- Additional monitoring campaigns shall focus on data gaps, causes of balancing residuals and acquisition of dynamic data. Basic checks of measurement and sampling procedures and data processing are to be performed beforehand
- Reconciled data set shall be used as the base for model calibration

THANK YOU FOR YOUR ATTENTION

- **Discussion topics (to be completed):**
  - ***Standardization of data evaluation methods***
  - ***What (of this procedure) could / should be automated ?***
  - ***Is there such a thing as ‘benchmark values’ or are ‘typical ratios’ too region specific and/or would be ‘general benchmark values’ be too broad in range in order to be applicable for data evaluation ?***