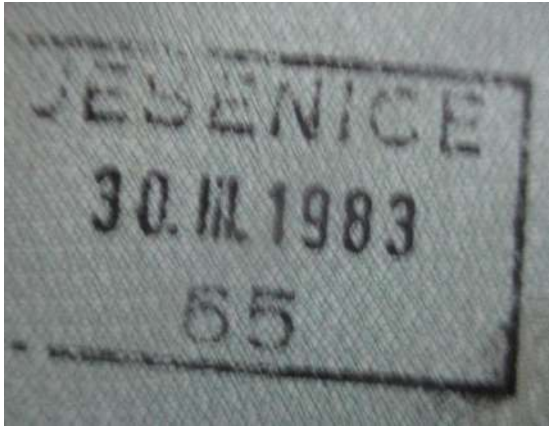
Integrated modelling and operation of sewer systems and wastewater treatment, considering river water quality

Dr Manfred Schütze
ifak e. V., Magdeburg/Germany

- **Many thanks for your invitation**



ifak e. V. Magdeburg

- Non-profit institute for applied research; 50 employees
- Associated to Otto-von-Guericke University of Magdeburg

- **Department „Water and Energy“**
  - Modelling and Simulation for planning, design and operation of urban water systems
  - Simulation and process control of
    - **Sewer system, WWTP, biogas, receiving waters, …**

www.ifak.eu
simba.ifak.eu

The German research landscape

The research system of universities and non-university institutions

- Universities
- German Research Mittelstand „Zuse association" … **ifak** …
- German research organisations FhG (Fraunhofer), HGF, WGL, MPG (Max Planck)

FhG Fraunhofer-Gesellschaft, HGF Helmholtz-Gemeinschaft, WGL Leibniz-Gemeinschaft, MPG Max-Planck-Gesellschaft

Simulator Simba#

Simba# - Simulator for modelling, systems analysis, optimisation and control

- Mainly for water systems (but also for other domains)
- Since 2013 as stand-alone program; used by researchers and practitioners worldwide

Simba#classroom – smaller version for lecturing and teaching

Combined Sewer Overflow Magdeburg (17.05.22)

Foto: © ifak

Among the objectives discussed in this presentation:

- Avoiding/Reducing negative impacts on the environment
- Maintaining standards
- Saving costs

When plannnig larger investments ...

- ... one would like to do a test-run

- Modelling
  - Strategic planning – to evaluate/compare different options
  - To assist / prepare the implementation
- Easier to do experiments in model than in reality

Perceived impediments to modelling:

- User-interface too complicated
- Data requirements
- Import of data
- Model connection (interaction of different models for different subsystems

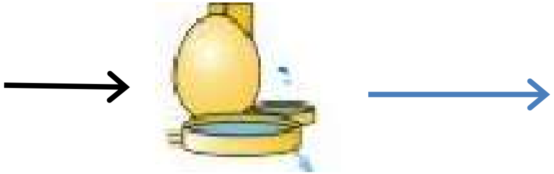
Perceived impediments to modelling:

- User-interface too complicated → GUI
- Data requirements → using available data
- Import of data → using GIS, Copernicus, …
- Model connection (interaction of different models for different subsystems)

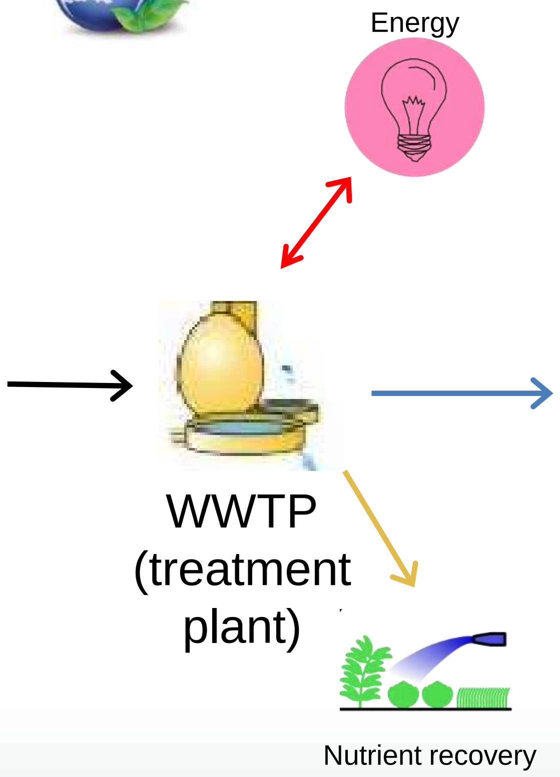
  → integrate in one simulator

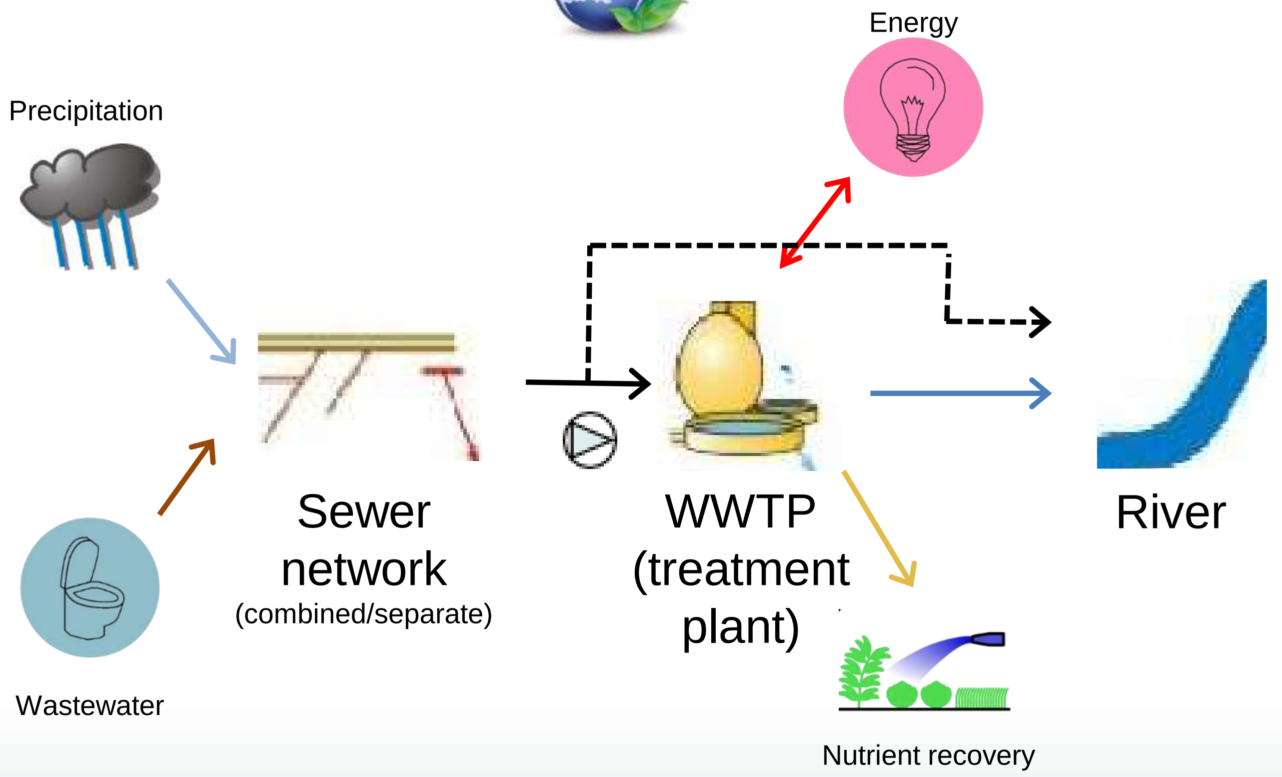
New challenges and topics:

- New requirements (e.g. new Urban Wastewater Directive, German DWA-A102, …)
- Environmental impacts (Greenhouse gases …)
- Drinking water scarcity; use of different water sources (e.g. greywater, …)



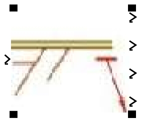
WWTP
(treatment
plant)


Energy
WWTP
(treatment
plant)
Nutrient recovery



Logos: © ifak, TU Berlin

Some important interactions in the wastewater system (especially after rainfall)



Sewer system

- flows
- „First flush“(?)

- increased WWTP influent
- sedimentation behaviour
- „First flush“(?)

WWTP

- sedimentation behaviour
- impact on treatment processes
- drop in temperature

•Nitrogen peaks
•Sludge loss from clarifier

- Combined sewer overflows

Receiving water body

- increased flow
- Oxygen decay
- Acute ammonia (NH_3) impacts
- Bacteria, toxic substances
- Mechanical impacts

<u>Timing of impacts plays an important role</u>

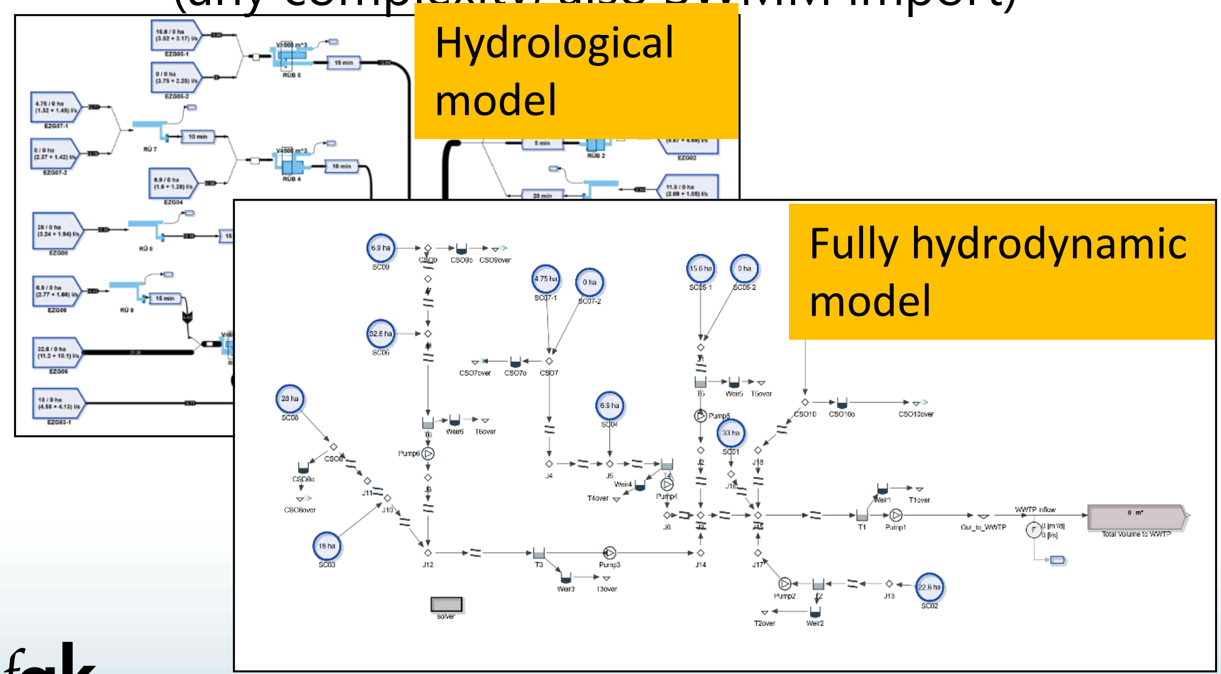
Sewer system modelling approaches:

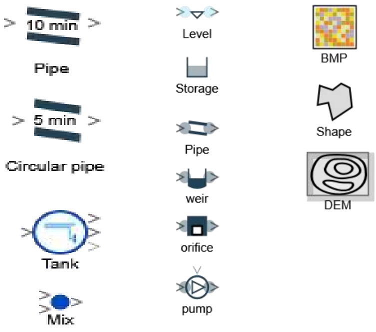
Process	Potential modelling approaches		
Rainfall-runoff	Constant runoff coefficient	Wetting losses, depression storage, etc.	Other (user-defined) approaches
Flow	Hydrologic (linear and non-linear reservoir cascades)	Diffusive-wave	Dynamic wave (full solution of Saint Venant equations)
Pollutant transport	None	Conventional (CSTR)	Lagrange (no numerical dispersion effects)
Physical-biochemical transformations	Simple sedimentation approach	Sedimentation and resuspension	Any transformation processes (Petersen-Gujer matrix)

Schütze (2017)

Sewer system modelling in Simba#

– (any complexity: also SWMM import)





SIMBA#

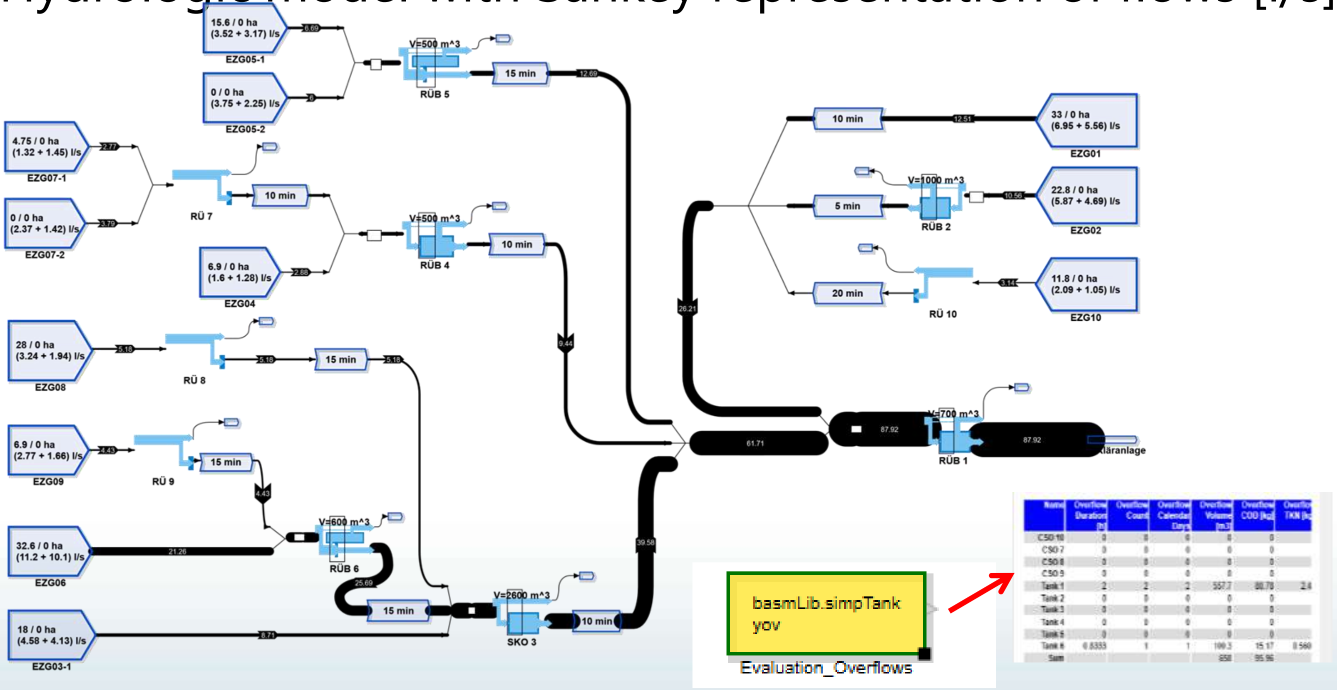
Hydrodynamic modules in Simba# allow:

- Full Saint Venant equations
- Pollutant transport: CSTR, Lagrange
- Any bio-chemical transformation processes
- Any form of control

- Import of SWMM files possible

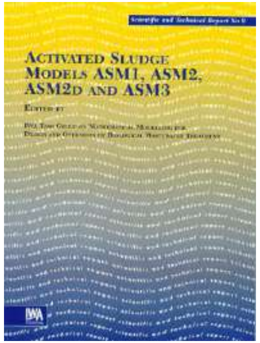
Sewer system modelling in Simba#

– Hydrologic model with Sankey representation of flows [l/s]



Wastewater treatment modelling

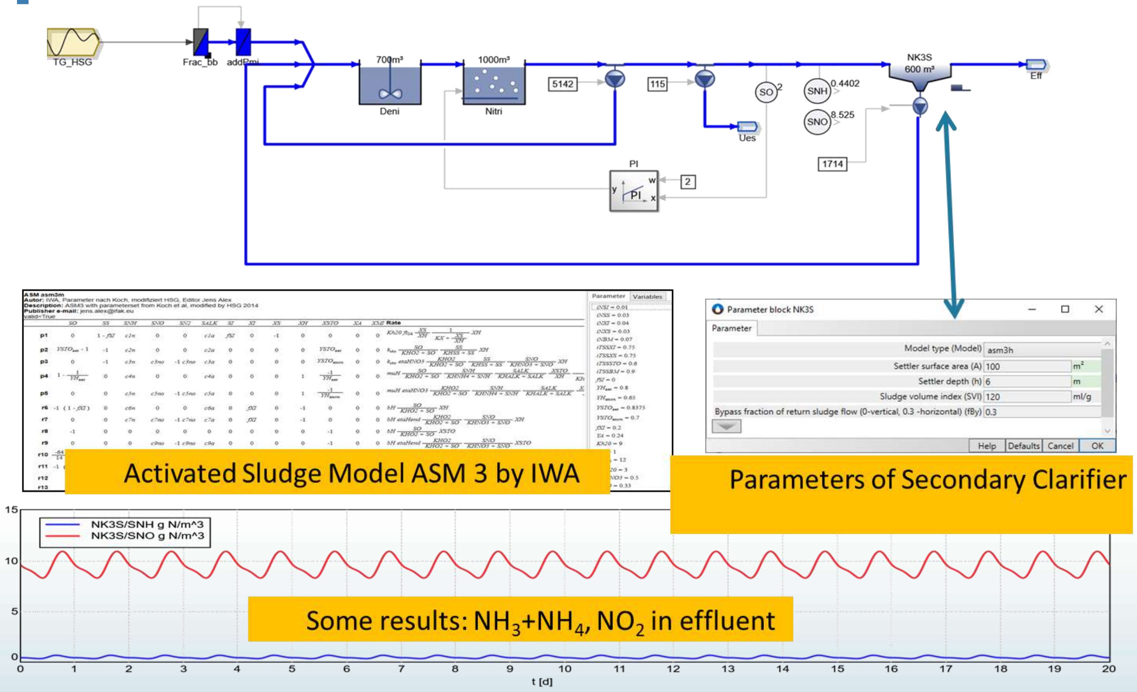
- **Detailed dynamic models (systems of differential equations)**
- **Modules for physical and biochemical processes:**
  - Primary clarifier, Secondary clarifier
  - Nitrification and denitrification tanks
  - Fourth treatment step
  - Control options, sensors, pumps
  - Aeration systems, Energy models
  - Sludge digestion
- **Useful for**
  - Selection of design variant, improvement of operation
  - Improvement of energy efficiency, …



The base of most biochemical process models for WWTPs

Wastewater treatment modelling

- A simple WWTP model

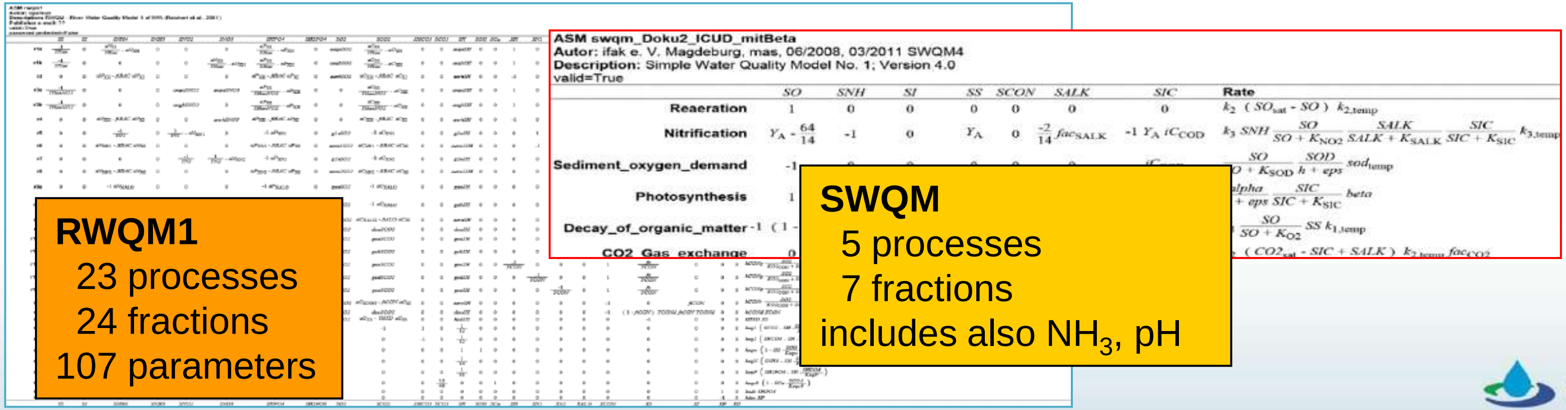


Wastewater treatment modelling

- **Influent definition in data-scarce situations**
  - "HSG" and "Case-C" methods
- **Some special modules:**
  - Membrane and biofilm reactors
  - Aeration systems in detail
  - Energy balances and analysis (DWA-A216 and EU)
  - 4th treatment step

River modelling

- **River water quality modelling in urban context:**
  - Impacts of sewer system and treatment plant discharges on river
  - Dissolved Oxygen, NH4, NH3, pH, …



River modelling

- **SWQM – A dynamic river model appropriate for practical application:**
  - Processes:
    - **Reaeration**
    - **Nitrification**
    - **Sediment oxygen demand**
    - **Photosynthesis (grossly simplified)**
    - **Decay of organic matter**

ASM swqm_Doku2_ICUD_mitBeta
Autor: ifak e. V. Magdeburg, mas, 06/2008, 03/2011 SWQM4
Description: Simple Water Quality Model No. 1; Version 4.0
valid=True

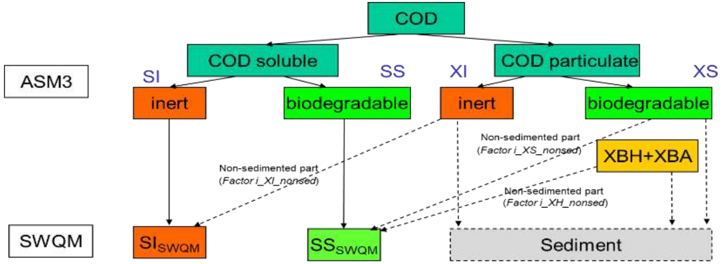
	SO	SNH	SI	SS	$SCON$	$SALK$	SIC	Rate
Reaeration	1	0	0	0	0	0	0	$k_2\ (SO_{sat} - SO)\ k_{2,temp}$
Nitrification	$Y_A - \frac{64}{14}$	-1	0	Y_A	0	$\frac{-2}{14} fac_{SALK}$	$-1\ Y_A\ iC_{COD}$	$k_3\ SNH \frac{SO}{SO + K_{NO2}} \frac{SALK}{SALK + K_{SALK}} \frac{SIC}{SIC + K_{SIC}} k_{3,temp}$
Sediment_oxygen_demand	-1	0	0	0	0	0	iC_{COD}	$\frac{SO}{SO + K_{SOD}} \frac{SOD}{h + eps} sod_{temp}$
Photosynthesis	1	0	0	0	0	0	$-1\ iC_{COD}$	$\frac{alpha}{h + eps} \frac{SIC}{SIC + K_{SIC}} beta$
Decay_of_organic_matt								$\frac{SO}{SO + K_{O2}} SS\ k_{1,temp}$
CO2 Gas exchang								$(CO2_{sat} - SIC + SALK)\ k_{2,temp}\ fac_{CO2}$

Process kinetics: based on state-of-the-art approaches (ASM3, RWQM1)

HESSEN

River modelling

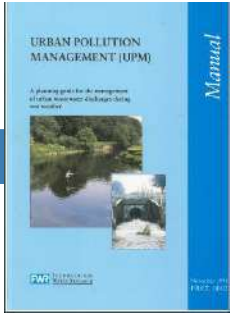
- **SWQM – A dynamic river model appropriate for practical application:**
  - Fractions:



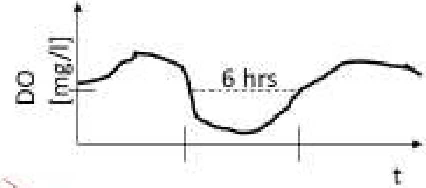
    - SO: Dissolved Oxygen
    - SNH: Ammonium/Ammonia (NH4-N+NH3-N)
    - SISWQM: soluble, inert COD fraction,
    - SSSWQM: soluble, biodegradable COD fraction,
    - SCON: conservative substance, e.g. for user-defined pollutants
    - SALK: Alkalinity (HCO3 equivalent)
    - SIC: inorganic carbon [SALK+CO2]

River modelling

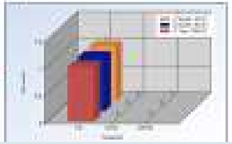
- **River modelling: Assessment of river water q acc. to UPM Manual**



- ☐ Duration-frequency criteria for DO:
- ☐ Exposure to a
  - concentration of ...4 ... mg/l for
  - more than ...6.... hours with a
  - return period of more than ... 1 year...



Return period	DO concentrations (mg/l)		
	1 h	6 h	24 h
1 month	4.0	5.0	5.5
3 months	3.5	4.5	5.0
1 year	3.0	4.0	4.5



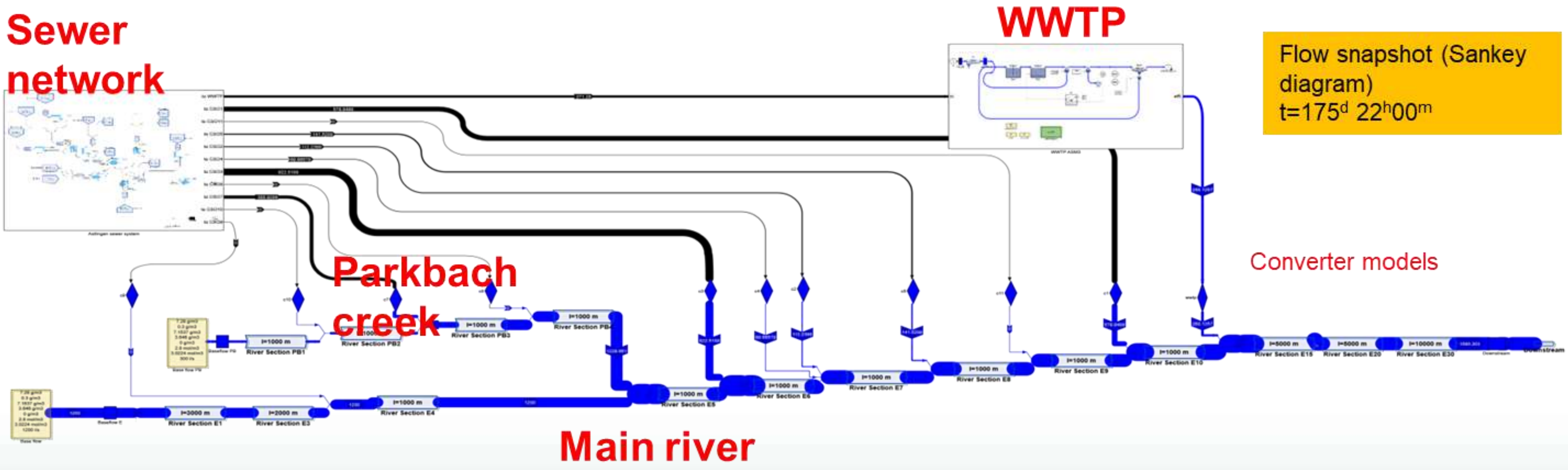
A related procedure also in DWA-M102-3:

River modelling

- **River modelling: Some Simba# specifics**
  - Possible flow modelling options: hydrologic, hydrodynamic
  - Pollutant transport: CSTR or Lagrange
  - Any biochemical model possible (e.g. RWQM, SWQM, …)
  - Evaluation routines (according to UPM and other guidelines)

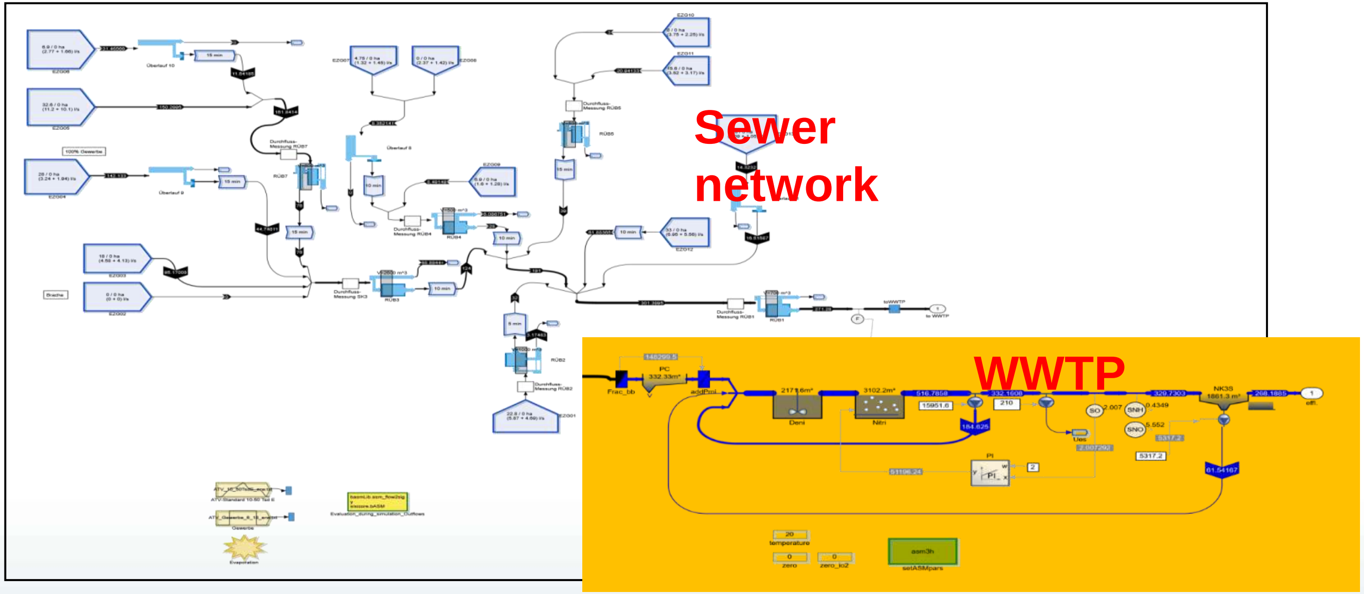
Example of an integrated model:

- Astlingen sewer network, WWTP and river



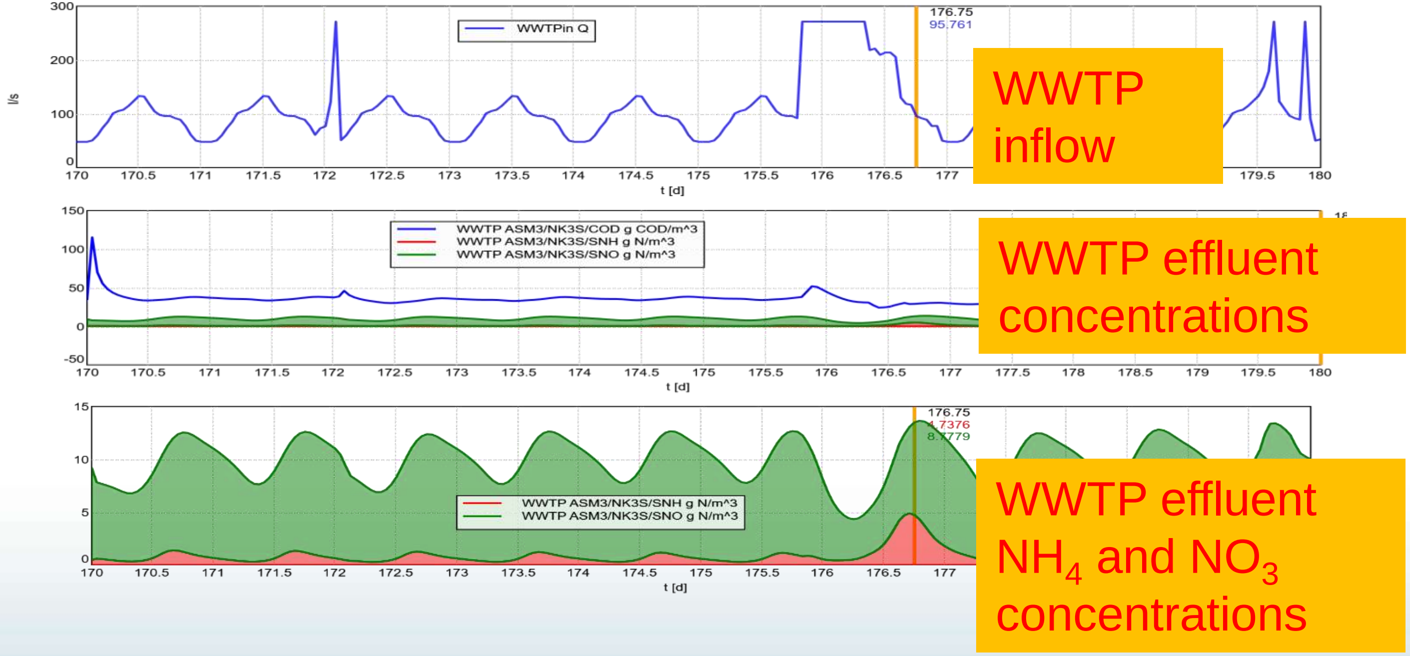
Example of an integrated model:

- Submodels:



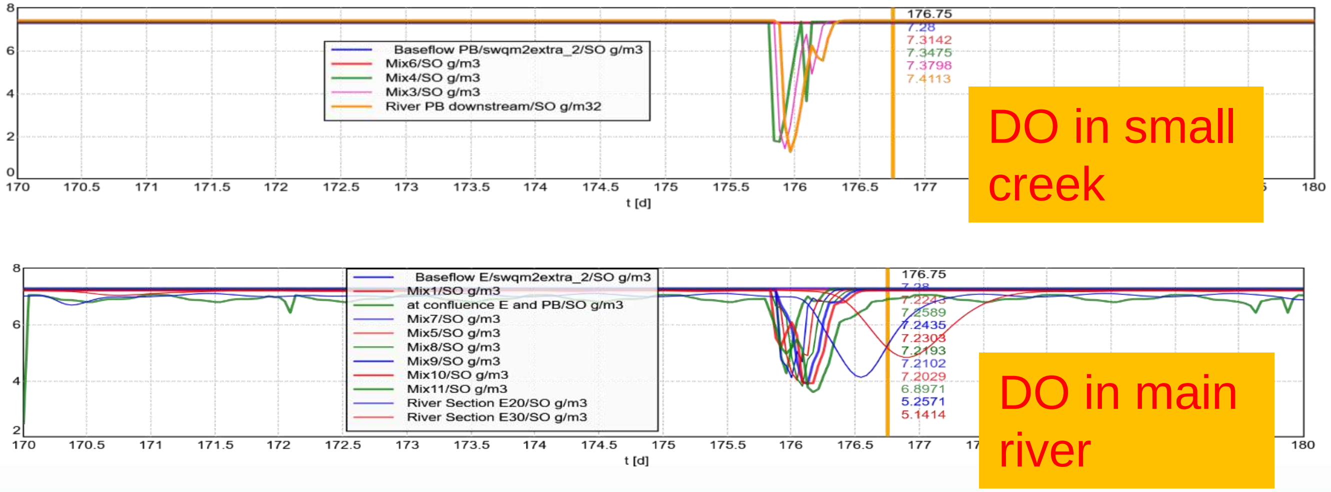
Example of an integrated model:

- **Simulation results: Base case**



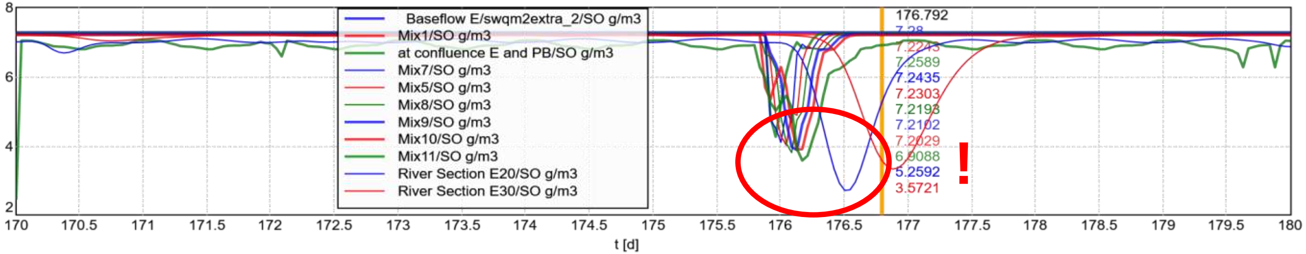
Example of an integrated model:

- Simulation results: River: Base case: Oxygen (DO)

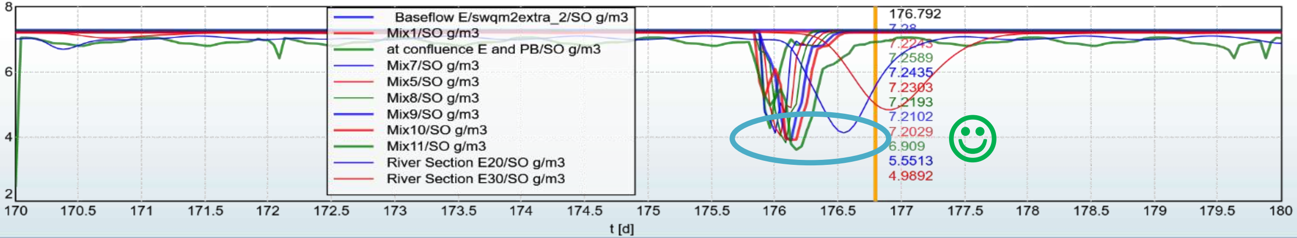


Example of an integrated model:

- **Simulation results: DO in various locations**
  - Q_{WWTPin} = 330 l/s permanently

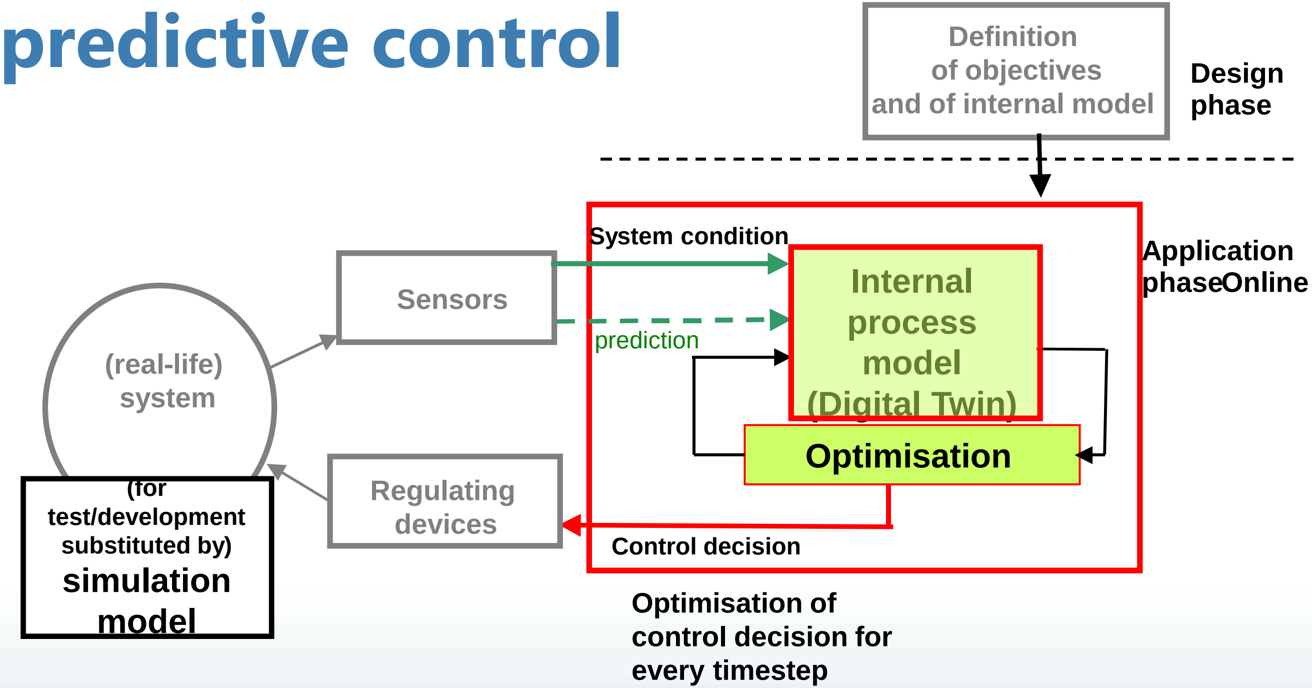


  - Q_{WWTPin} = 330 l/s for max.1 hr within any 24-hour period



Additional topics (1):

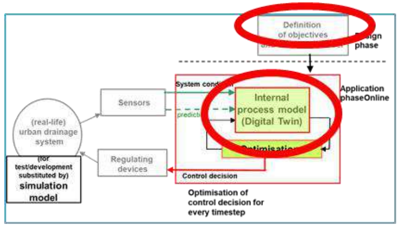
- Model-based predictive control

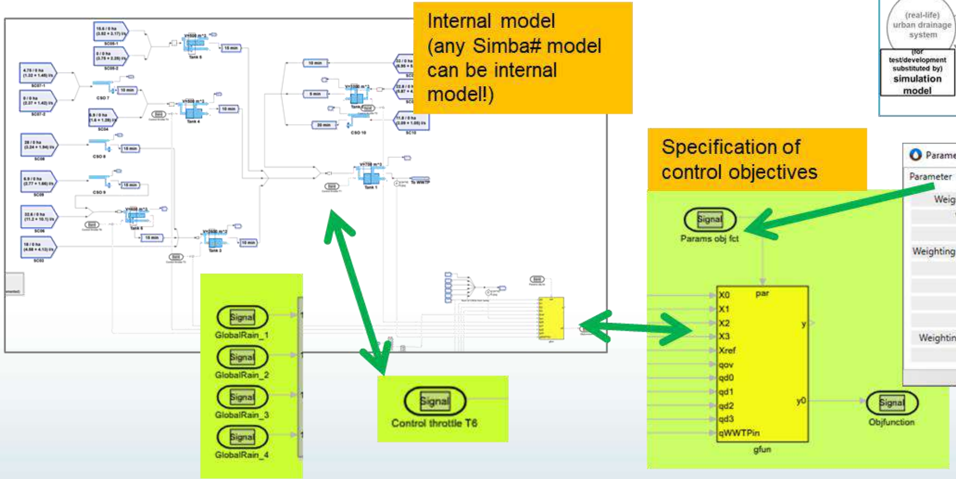


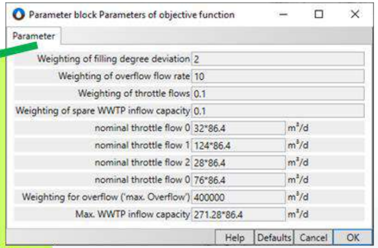
- Internal process model called many times
- Set-up and implementation so far requires special software

Additional topics (1):

- ## Model-based predictive control: Example
  – Controlling 4 tanks in Astlingen sewer system
  Main objective: Minimisation of CSO volume






Parameter block Parameters of objective function

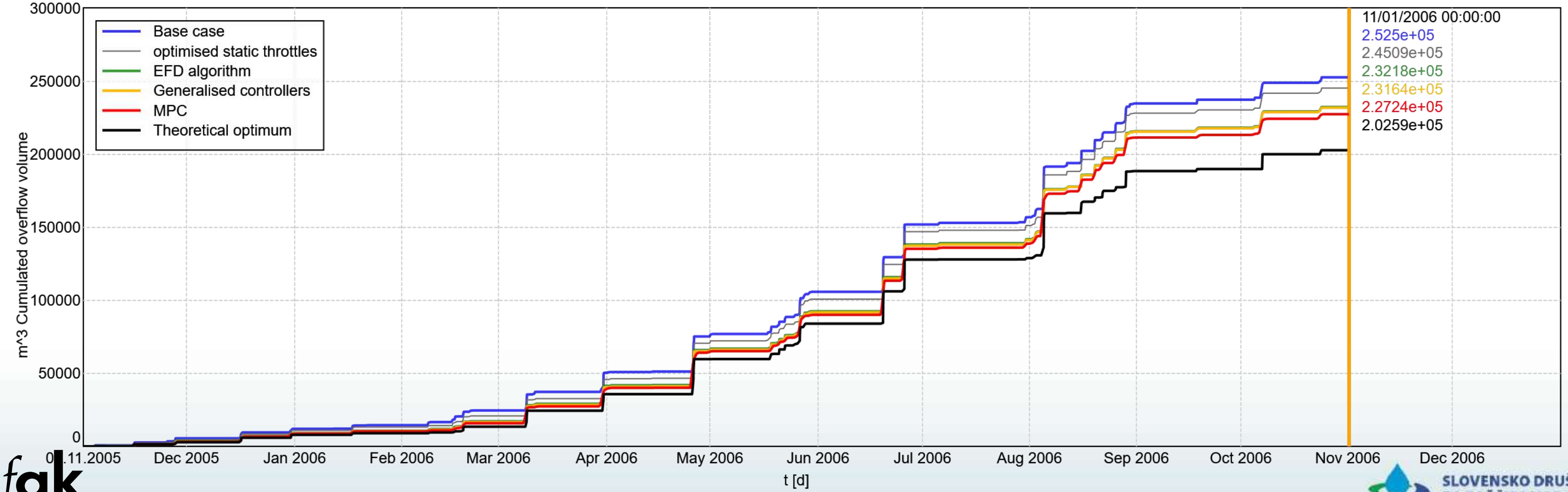
Parameter

Weighting of filling degree deviation	2	
Weighting of overflow flow rate	10	
Weighting of throttle flows	0.1	
Weighting of spare WWTP inflow capacity	0.1	
nominal throttle flow 0	32*86.4	m^3/d
nominal throttle flow 1	124*86.4	m^3/d
nominal throttle flow 2	28*86.4	m^3/d
nominal throttle flow 0	76*86.4	m^3/d
Weighting for overflow ('max. Overflow')	400000	m^3/d
Max. WWTP inflow capacity	271.28*86.4	m^3/d

Help Defaults Cancel OK

Additional topics (1):

- **Model-based predictive control: Example: Results**
  - CSO volume over 1 year – different control approaches



Additional topics (1):

- ## Model-based predictive control: Project i-SEWER

„Digital GreenTech – Langprojekt i-SEWER: Die nächste Generation der Kanalnetzsteuerung“ (BMBF, 02WDG1641, 04.2022- 03.2024)

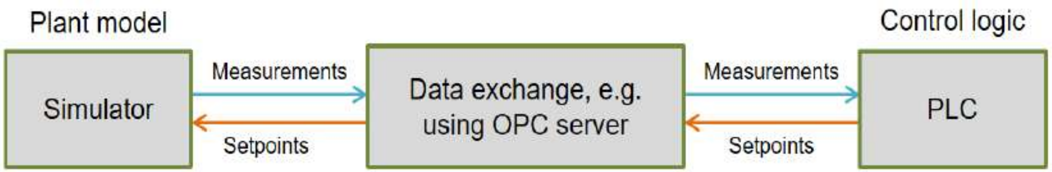
- ☐ Can the internal model be „learned“ applying AI technologies?
- ☐ Analysis for the sewer network of city of Freiburg (Brsg.)

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

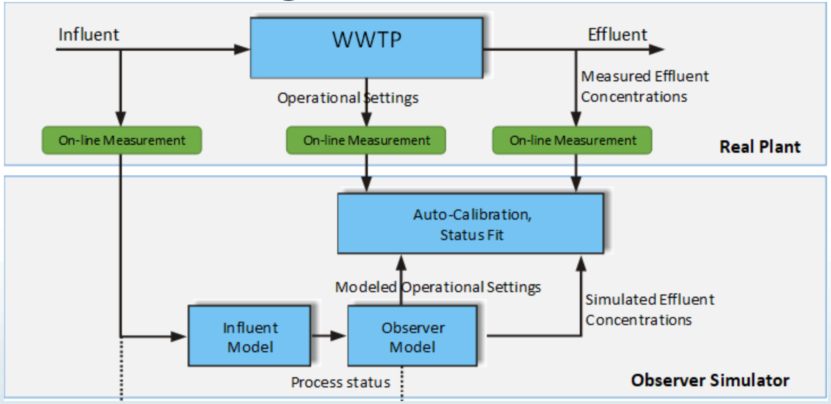
UFZ HELMHOLTZ Zentrum für Umweltforschung
Grimm Water Solutions
ifak Institut für Automation und Kommunikation
Eigenbetrieb Stadtentwässerung | Freiburg im Breisgau
bnNETZE Zuverlässig und vor Ort
BIT INGENIEURE
AZV ABWASSERZWECKVERBAND BREISGAUER BUCHT

Additional topics (2):

- **Connecting the model with the real world**
  - Virtual commissioning:



  - Observer model: Getting more information out:

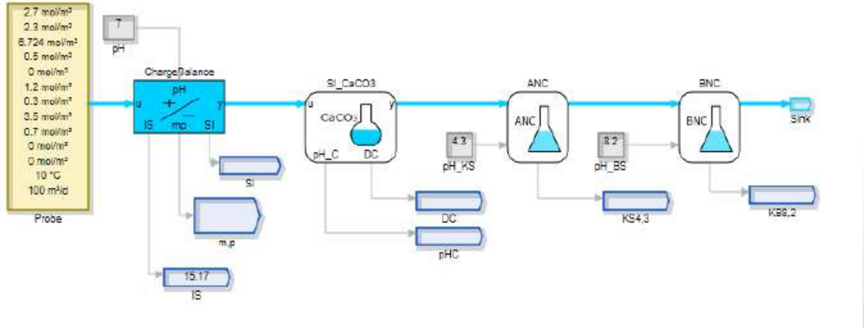


Additional topics (2):

- Connecting the model with the real world
  - Option 1: Use ifakFAST tool
    - Free of charge, open source
  - Option 2: Use HTTP-REST-API of SIMBA
    - Maximum flexibility
    - Detailed knowledge required about the API / C# scripting
    - Programming effort

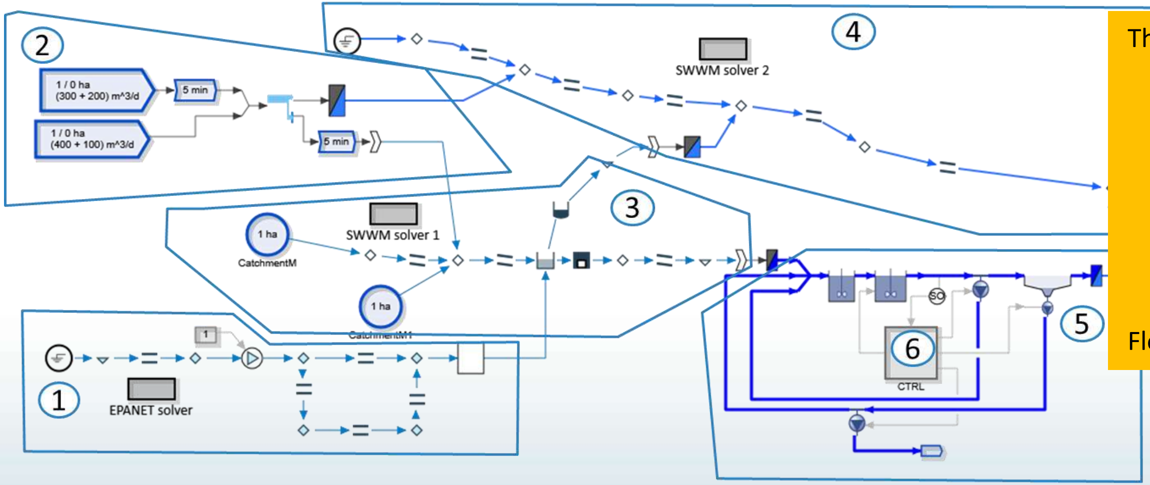
Additional topics (3):

- **Drinking water ion balance in Simba#**
  - based on DIN 38404-10
  - Corrects measured values of aqueous solutions: Charge balance, ionic strength, …..
  - Calculates pH, alkalinity, buffer capacities and hardness



Additional topics (4):

- **Multi-solver environment**
  - Making optimum use of dedicated numerical solvers for subsystem, yet connecting everything to one model



This simple example combines:
1 Pressured pipe network solver (EPANET)
2 Discrete-time model (hydrologic sewer)
3 Saint Venant (hydroynamic sewer)
4 Saint Venant (hydrodynamic river)
5 ODE+equation solver (WWTP)
6 Instrumentation, Control and Automation
Flow and water quality in each component

Conclusions

- **Planning, operation can be assisted by modelling**
- **Simba# simulator**
  - Useful for enduser: Output and report options, ...
  - Useful for researchers: user-defined modules and scripts, User-friendly process equation editorSimba#classroom: simplified version for classroom teaching
- **Feel encouraged to build and apply simulation models for your tasks!**

DBU Scholarship programme

- 6 – 12 stay in Germany working on a topic related to environment
- Full scholarship (EUR 1350 per month + insurances)
- Many host institutions (including ifak)
- More details:

  https://www.dbu.de/foerderung/moe-fellowship/
- Application: every year on 05.09. and 05.03.

DBU Deutsche Bundesstiftung Umwelt www.dbu.de

Najlepša hvala! Many thanks!

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