11e Conférence internationale
LYON 2023 — L'eau dans la ville | Urban water

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L'eau dans la ville | Urban water

A Digital Twin platform for purpose-driven modelling

Une plateforme jumeau digital pour une modélisation axée sur ses objectifs

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Ifak e. V. Magdeburg

Context: ZwillE research project

"ZwillE – Digital twin for an AI-assisted management of extreme water events in urban areas"

- https://zwille-projekt.de/

Project partners:

Stadtentwässerung Hannover – Wir klären das. | Ingenieurgesellschaft für Stadthydrologie mbH (ifs) | hydro & meteo | IAB Institut für Angewandte Bauforschung Weimar | ifak | Atos

- Funding (02/2022 – 01/2025):

Sponsored by the Federal Ministry of Education and Research | FONA Nachhaltiges Wassermanagement | WaX Wasser-Extremereignisse

Context: ZwillE research project

Objectives of ZwillE project:
- Resilient and sustainable urban wastewater infrastructure systems
- Assuring safe wastewater management also under hydrologically extreme conditions

To be achieved by:
- Improved prediction of extreme situations
- Proactive reduction of impacts of extreme events (short-term control in acute situations; long-term planning for adaptation of infrastructure)
- …
- Example case: Wastewater system of city of Hannover/Germany

Context: ZwillE research project

Selected aspects:
- **Rainfall nowcasting and prediction:**
  Tuesday, Poster Session:
  „Advanced real-time precipitation components for urban hydrological applications as part of a digital twin for the city of Hanover“
  Thomas Einfalt, Alrun Jasper-Tönnies, Manfred Schütze, Erik Ristenpart, Alexander Strehz
- **Setting up a Digital Twin:**
  - Covers many different aspects
  - Focus here: implications for sewer system modelling

The ZwillE Digital Twin use cases

Use Case 1

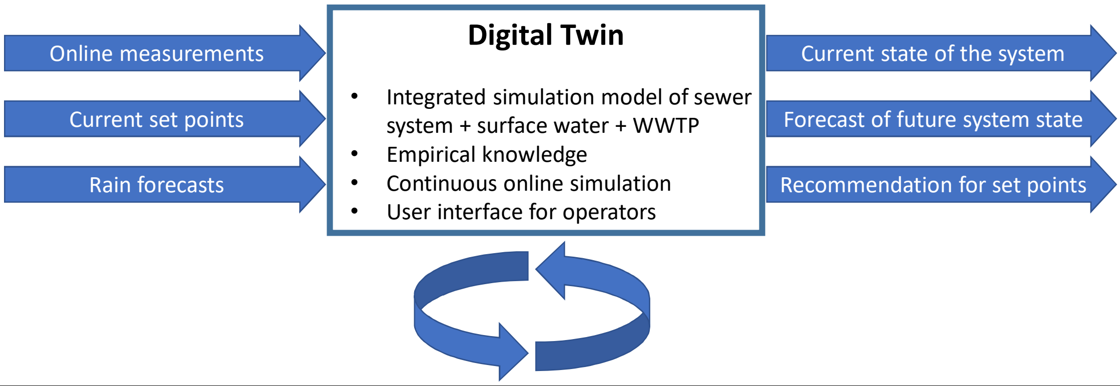
Online modelling (representation of current state of the wastewater system)

Use Case 2

Short-term planning during acute events (e.g. control)

Use Case 3

Long-term strategic planning (to prepare for future) (e.g. infrastructure: sewer system, WWTPs)



The ZwillE Digital Twin: Challenge No. 1: Modelling requirements

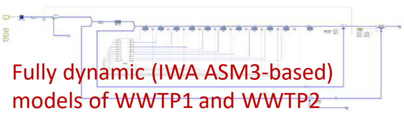
- Different use cases have different requirements, for example with regard to:
  - Simulation speed
  - Degree of detail
  - Visualisation

- Traditional approach: Use of different types of simulation models,
  e.g. (for sewer systems):
  - Hydrological sewer models
  - Hydrodynamic sewer models

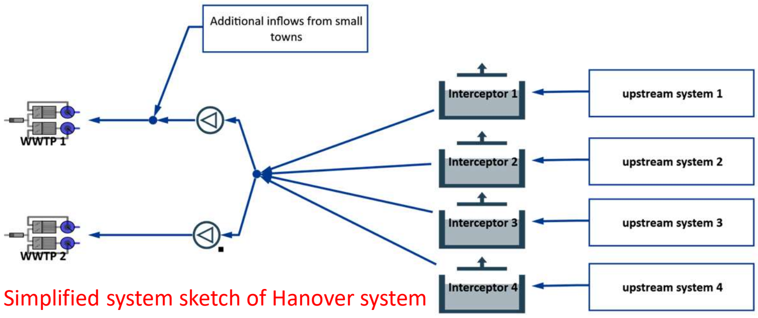
  -> Maintaining two different models (usually in different software packages)

Case study: Hanover/Germany

- Hanover region: approx. 750000 inhabitants
- Flat sewer system, 4 main interceptor sewers
- 2 WWTPs (jointly: 1.25 million PE)
- Relatively small receiving water (flooding; affecting CSO options)



Fully dynamic (IWA ASM3-based) models of WWTP1 and WWTP2

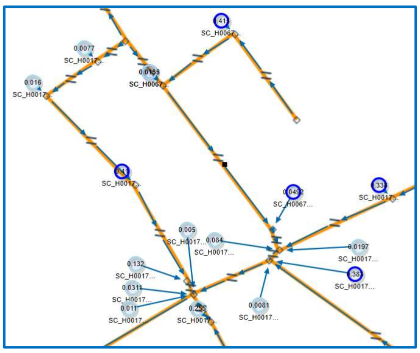


Simplified system sketch of Hanover system

Modelling base

I. Detailed hydrodynamic model

- Implemented in Simba# simulator
- Set up/combined with GIS features

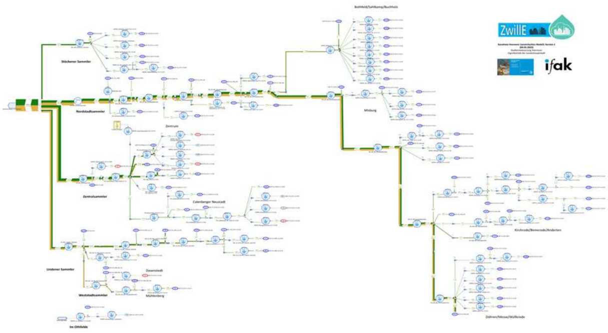


Detailed hydrodynamic model:
33446 Subcatchments
41139 Pipes
38565 Junctions
…
+ Weirs
+ Pumps
+ Orifices
+ Outlets

Modelling base

II. Hydrological (simplified) model,

- Implemented in Simba# simulator
- DWA A102-compatible



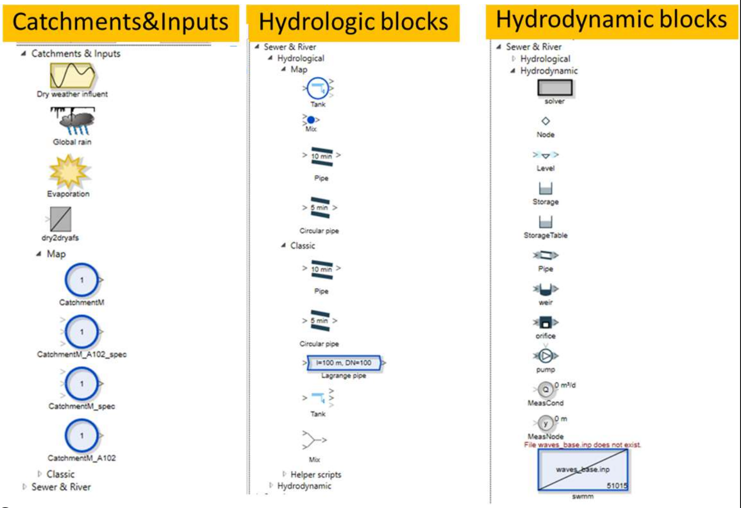
<u>Hydrological model:</u>

- 92 Subcatchments, each with 4 subcategories (acc. to DWA A102-2 runoff-pollution)
- 95 Tanks and CSO structures
- 84 Collectors

Modelling base: Simba# simulator

The Simba# simulator

- Sewer systems:
  - Rainfall-runoff processes
  - Hydrologic modelling
  - Hydrodynamic modelling
  - Combinations thereof
  - Control (arbitrary control concepts, e.g., IEC 61131-ST, MBPC)
  - Optional: pollutants
- Integrability with WWTP and river
- ifakFAST (open source) interface for connection with SCADA and PCS

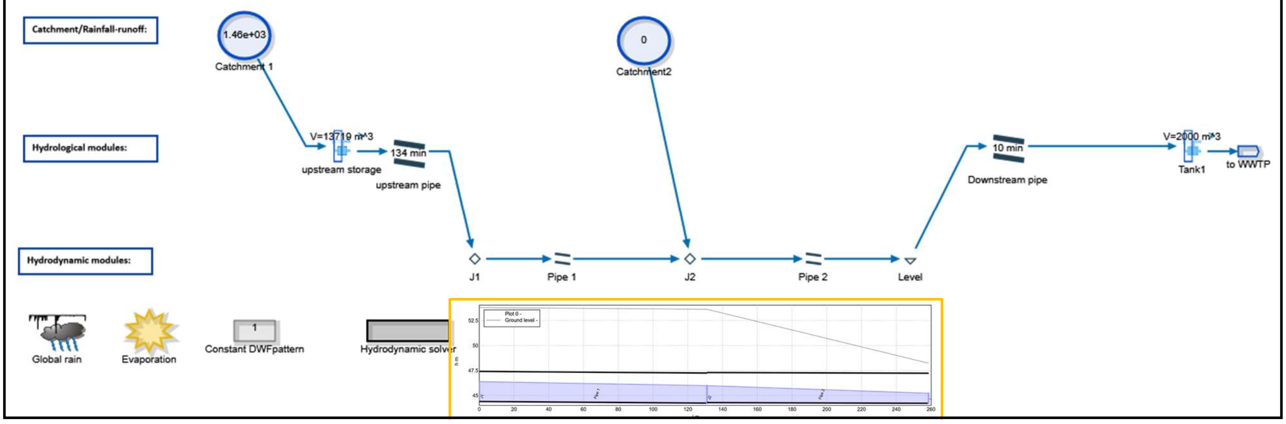


Modelling base

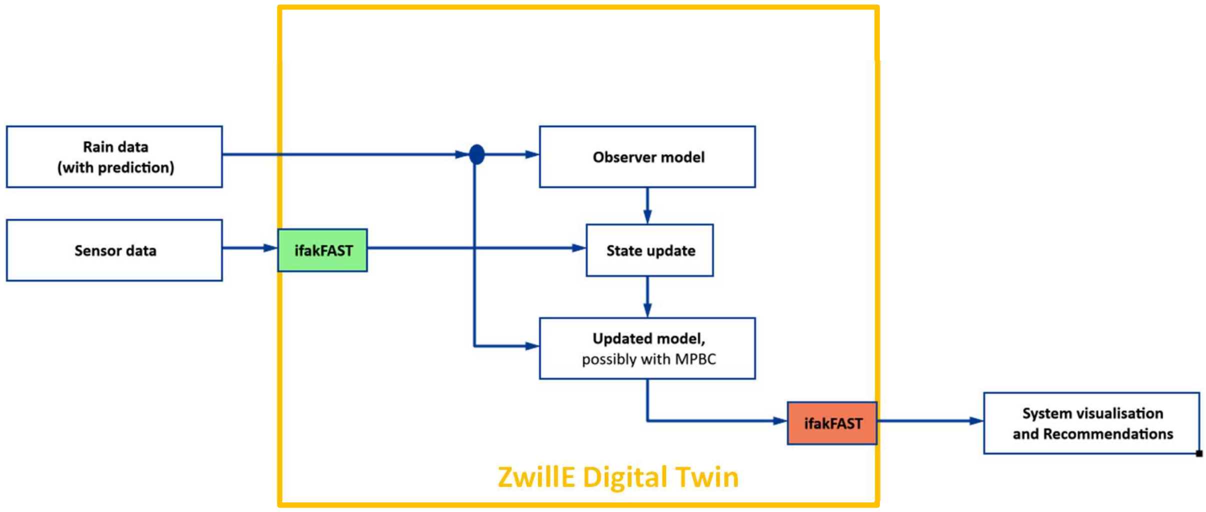
Challenge: Importance of flat interceptors

- one model too complex, one model too simple

-> Solution: Combining modelling approaches within one model



Draft model architecture of the Digital Twin



The ZwillE Digital Twin: Challenge No. 2: Data access/management

Challenge: Wastewater system = Critical infrastructure:

- Data security is of very high importance
- Municipal wastewater company is careful about providing data access

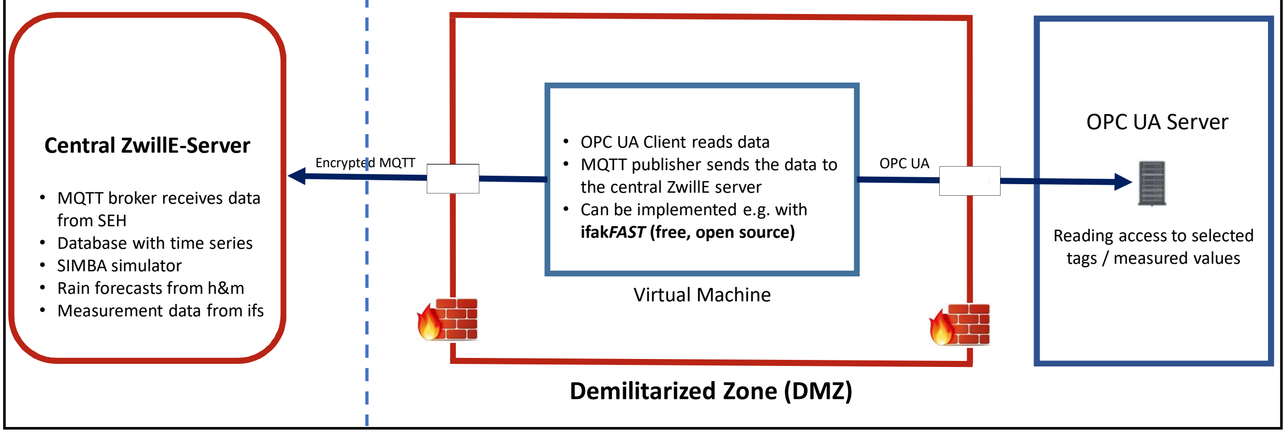
Solution: Data for the Digital Twin written to external server

- See next slide

The ZwillE Digital Twin: Data access/management

ZwillE Coordinator (ATOS)

Municipal wastewater company (SEH)



Some pitfalls in model evaluation

Some discussions in the development process of the Digital Twin:

- Individual events vs. continuous simulation
- Assessment criteria for model fitting

Some pitfalls in model evaluation: Event-based evaluation vs. Long-series

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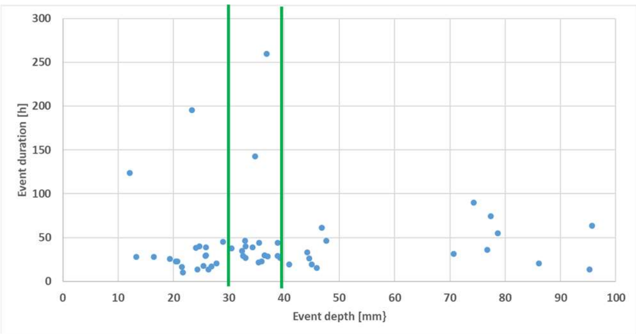
- Modelling example: Evaluation of RTC potential over 1 year:
  - MPC as compared to local control: 10 % Reduction of CSO volume
- Event-based evaluation (using following – simplfied – event defintion):
  - Start: if at least one raingage > 0 mm
  - End: if all raingages = 0 for at least 6 hours
  - Overflow event: if CSO in base case
- -> 54 CSO events (on average: 34 % reduction of CSO volume)
- Event-based evaluation:

		% of 54 events	
% Reduction	Reduction of CSO volume	MBPC	
< 0	getting worse	1,9	10 %
0 bis 0.1	practically same as before	7,4	
0.1 - 5	very slight reduction	14,8	40 %
5 - 20	slight reduction	25,9	
20 - 50	significant reduction	22,2	50 %
50 - 99	very significant reduction	16,7	
100	No CSO overflow at all by control	11,1	
		100,0	

Some pitfalls in model evaluation: Event-based evaluation vs. Long-series

- Evaluation over (deliberately) selected events:



- Caution: Event-based evaluatoin can be misleading
- Besser: Langzeitauswertung!

- Grouping of events into 6 subgroups
- Selecting one event per subgroup
- Results with regard to this selection:
  a) Deliberately „against control“

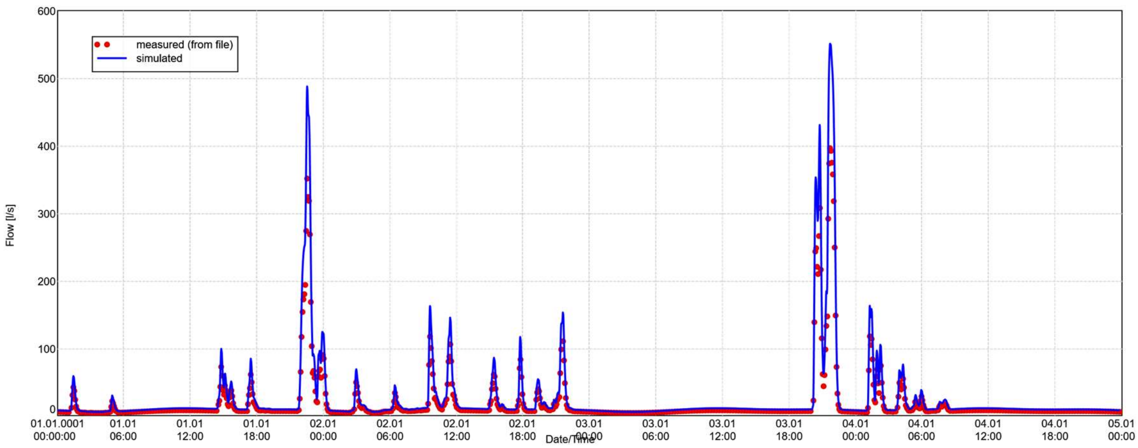
Events with SMALL %CSO Volume reduction	
Event #	% Reduction (MBPC)
43	0
36	22
26	17
37	3
41	6
6	14
Average of these 6:	10

  b) Deliberately „for control“

Events with LARGE %CSO Volume reduction	
Event #	% Reduction (MBPC)
2	100
8	100
17	66
15	100
24	6
3	27
Average of these 6:	67

Some pitfalls in model evaluation: Assessment of model fitting

- How would you assess this fit between measured and simulated data?



Some pitfalls in model evaluation: Assessment of model fitting

- How would you assess this fit between measured and simulated data?

Explanation table (according to Zior (1987)

ID	Name	Unit	Very good	good	satisfactory	not satisfactory
DEVS	Hydrologic Deviation	[%]	0..3	3..10	10..18	> 18
DEVM	Modified Hydrologic Deviation	[%]	0..15	15..30	30..50	> 50
STAN (=NSE)	Modified Standard Deviation (Nash-Sutcliffe Efficiency)	[-]	1.0..0.85	0.85..0.65	0.65..0.35	< 0.35
VOL	Volume balance	[-]	abs < 0..5	abs < 5..10	abs < 10..15	abs > 15
HScore	Henrichs' score	[-]	1..1.5	1.5..2.5	2.5..4.5	> 4.5
MAE	Mean Absolute Error	[-]				
RMSE	Root Mean Square Error	[-]				
NNSE	Normalised NSE	[-]				
DYMAX	Difference in maximum value	[%]				
Pears-R	Pearson correlation coefficient	[-]				
KGE_SD	Kling-Gupta Efficiency 2009 (using alpha)	[-]				
KGE_CV	Kling-Gupta Efficiency 2012 (using gamma)	[-]				

Name	Unit	Value	Interpretation
DEVS	[%]	1.12	very good
DEVM	[%]	24.19	good
STAN (=NSE)	[-]	0.97	very good
VOL	[%]	-28.29	not satisfactory
H-Score	[-]	2.55	satisfactory
MAE	[-]	623.61	
RMSE	[-]	1601.32	
NNSE	[%]	0.97	
DYMAX		-28.09	
Pears-R	[-]	1	
KGE_SD	[-]	0.44	
KGE_CV	[-]	-0.02	

Assessment in model fitting: Some commonly applied criteria:

With y_i (i=1,..,n) the simulated values (equidistant),
z_i (i=1, .., n) the measured values **(equidistant)**,
n: number of values to be compared
y_{mean} := Mean (y_i)
z_{max} := Max (z_i); z_{mean} := Mean (z_i)

Hydrologic Deviation DEVS:

$$DEVS := 200 \frac{\sum |y_i - z_i| * z_i}{n * z_{max}^2}$$

Volume balance VOL:
With
V_y: Volume (Integral) of simulated values,
V_z: Volume (integral) of measured values

$$VOL := 100 \frac{V_z - V_y}{V_y}$$

Root Mean Square Error RMSE:

$$RMSE := \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - z_i)^2}$$

Modified Standard Deviation after Maniak (STAN); Nash-Sutcliffe Efficiency (NSE):
With

$$R_0^2 := \frac{1}{n}\sum_{i=1}^{n}(z_i - z_{mean})^2 \quad \text{and} \quad R^2 := \frac{1}{n}\sum_{i=1}^{n}(z_i - y_i)^2$$

$$STAN := NSE := \frac{R_0^2 - R^2}{R_0^2} = 1 - \frac{R^2}{R_0^2}$$

NSE has a value within the interval [-∞; 1] with
NSE = 1 indicating a perfect match,
NSE = 0: simulated value corresponds to mean of measured values
NSE < 0: mean of measured values representing a better prediction than the results of the simulation

Henrich's Score (Henrichs, 2015):
- *Combination of NSE, VOL, DYMAX*
- German school marks
- (1=very good; 5=complete failure)

Implemented criteria

ID	Name of hydrologic error criteria	Unit
DEVS	Hydrologic Deviation	[%]
DEVM	Modified Hydrologic Deviation	[%]
STAN (=NSE)	Modified Standard Deviation (Nash-Sutcliffe Efficiency)	[-]
VOL	Volume balance	[-]
MAE	Mean Absolute Error	[-]
RMSE	Root Mean Square Error	[-]
NNSE	Normalised NSE	[-]
DYMAX	Difference in maximum value	[%]
HScore	Henrichs' score (combined from NSE, VOL, DYMAX)	[-]
Pears-R	Pearson correlation coefficient	[-]
KGE_SD	Kling-Gupta Efficiency 2009 (using alpha)	[-]
KGE_CV	Kling-Gupta Efficiency 2012 (using gamma)	[-]
alpha	for KGE: alpha [Stddev(simul)/Stddev(meas)]	[-]
beta	for KGE: beta [Mean(simul)/Mean(meas)]	[-]
gamma	for KGE: gamma [Var(simul)/Var(meas)]	[-]

Conclusions / Key issues

- Different use cases might require different digital twins.
- Models of different degree of complexity can be "merged".
- A concept for safe data processing and for connection of the model to the world has been proposed.
- A unified model setup supports development and application of digital twins.

- Some work still needs to be done for the ZwillE Digital Twin.
- Exciting potential extensions:
  - Besides coupling with pumping stations and WWTP models, also other Simba# models (e.g. drinking water networks) could be integrated
  - Integration of RTC concepts (e.g. MBPC, as any Simba# model can be used as an internal model for MBPC).

Thank you!

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