Conceptual modelling of water systems

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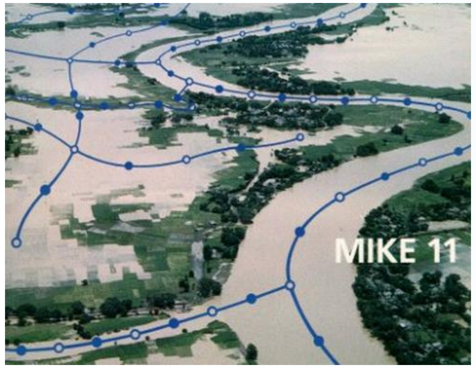
Introduction

- Evolution towards integrated water management at basin scale

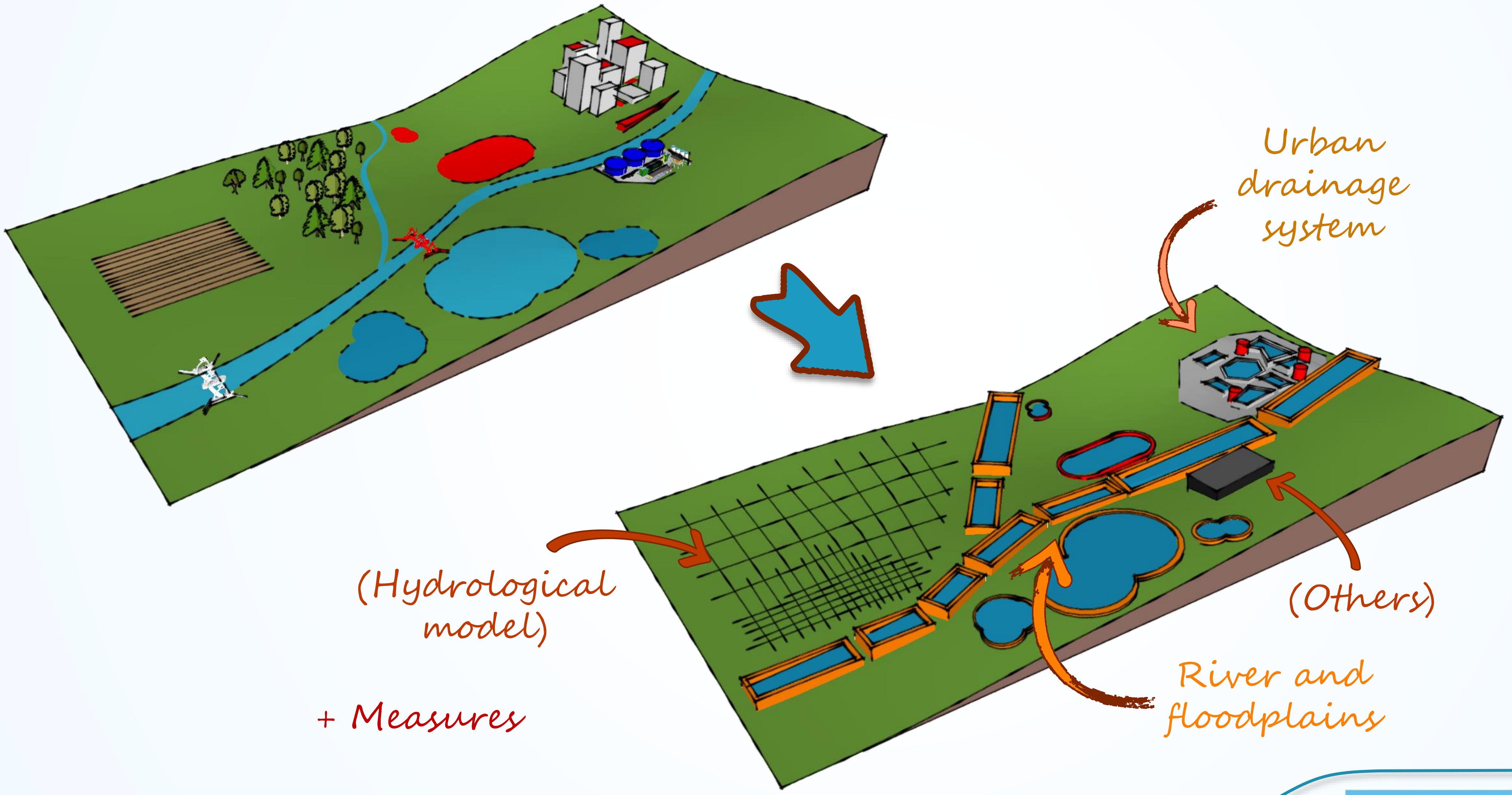
- Wide range of desired applications
  - Decision support: scenario analyses
  - Warning systems
  - Real time control
  - …



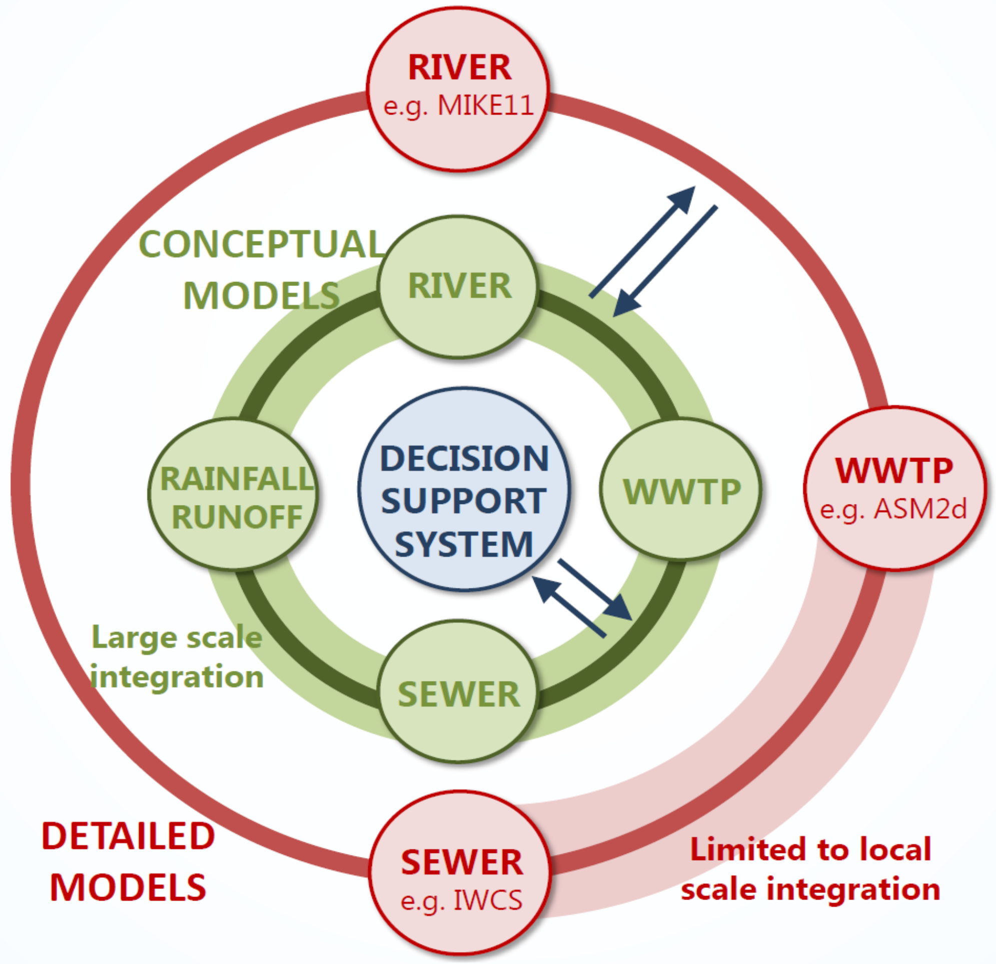
- Problems current modelling tools:
  - Calculation time
  - Technical complexities with coupling
  - How to use sensors (“big data”) most effectively?
  - Different time and space scales

➔ **Need for an “alternative” modelling system**

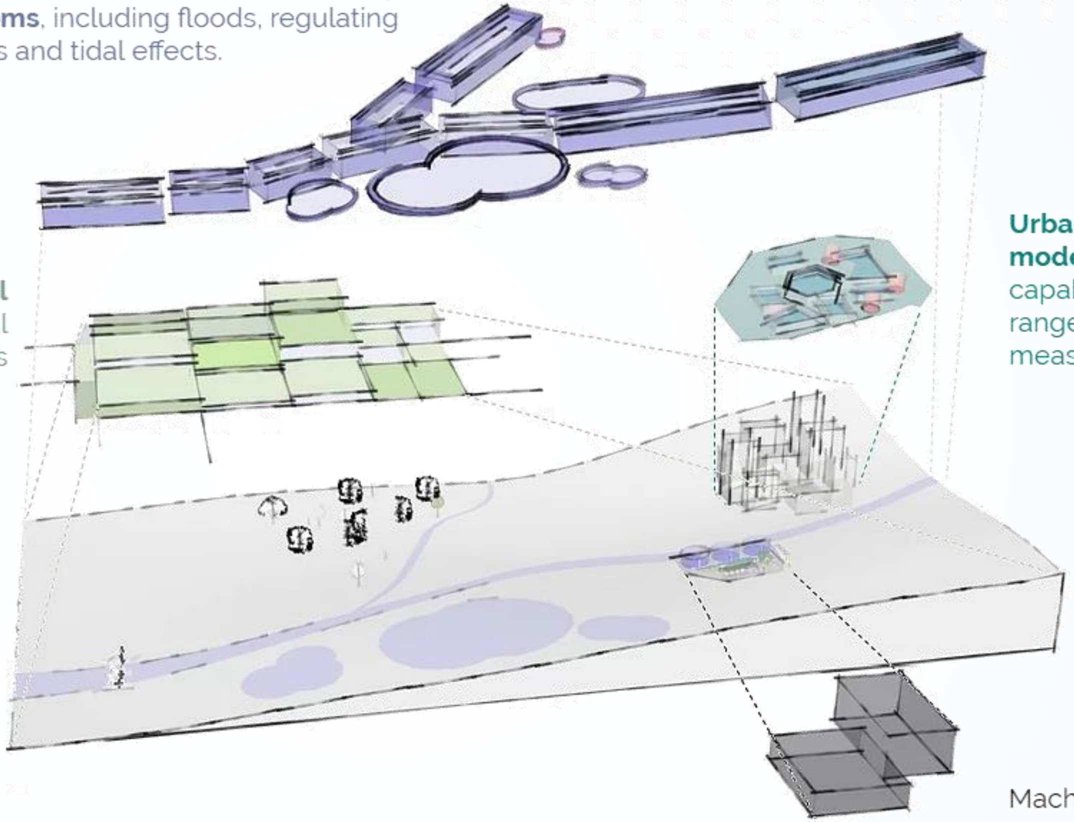
Integrated water system approach



Conceptual vs. hydrodynamic models



Conceptual models



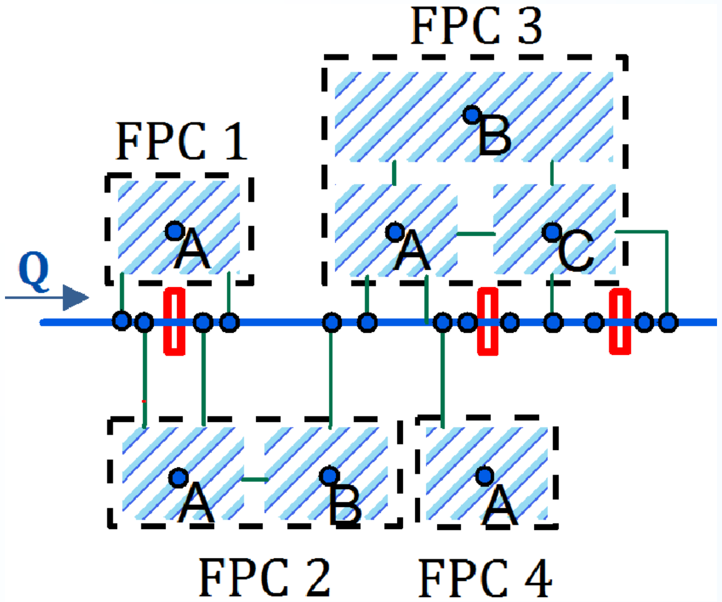
- ✓ Integrated catchment scale
- ✓ Super fast
- ✓ Flexible: adjustable level of detail, “tailored” to the application
- ✓ Accurate (if well calibrated)

The basic modelling principles

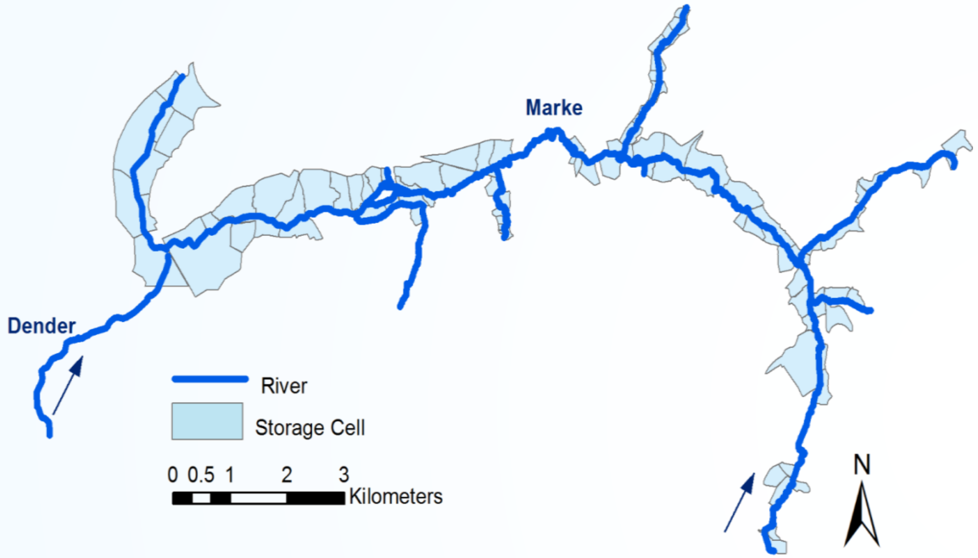
- Surrogate "conceptual" models to emulate components
  - Data-driven
  - Mechanistic
  - Use simulation results of detailed hydrodynamic models

- Storage cell concept
  - Lump processes
  - Close water balance explicitly

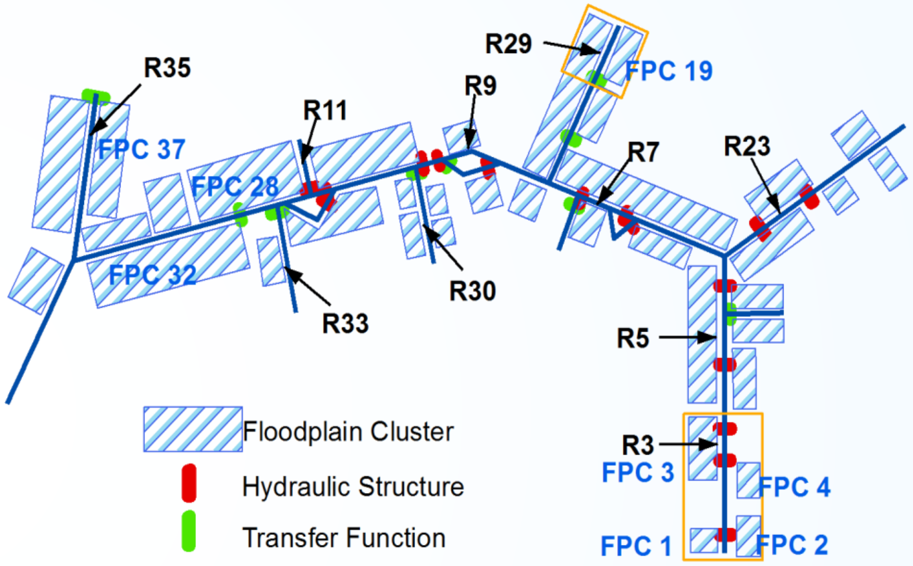
- Modular framework
  - Process-based equations
  - ANN, M5', fuzzy systems, …



Example: River Marke (Belgium)



InfoWorks RS model

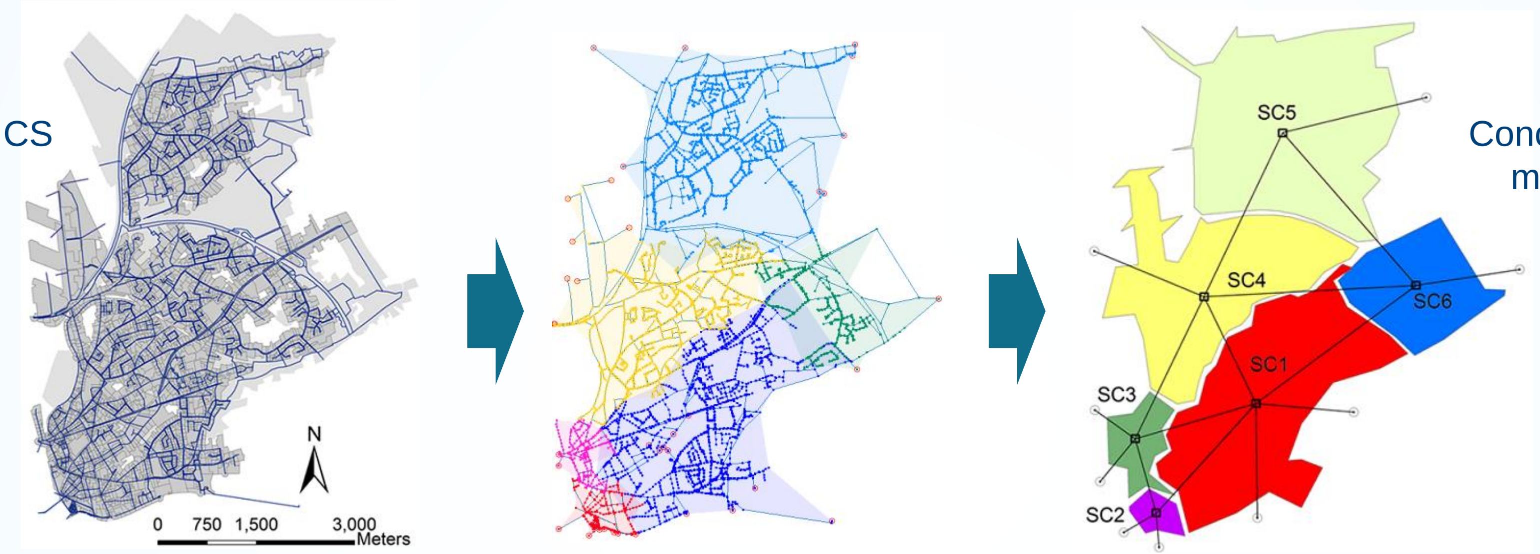


Conceptual model

- ✓ >800 calculation nodes
- ✓ Incorporation of controllable hydraulic structures & dike levels
- ✓ Discrete calculation scheme with adaptive time step
- ✓ Simulation time one-month event: 1.12 seconds (gain ~ factor 2000)

Example: Sewer system city of Gent (Belgium)

InfoWorks CS



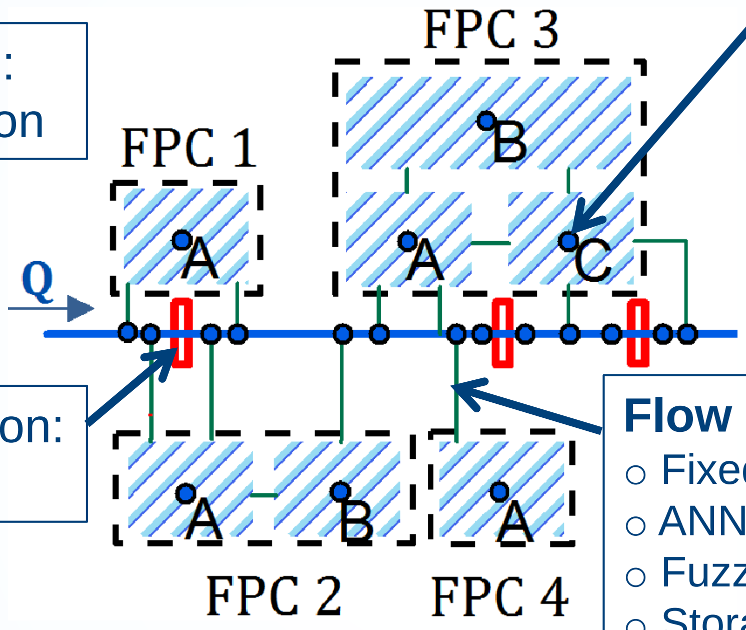
Conceptual model

- ✓ All sewer overflows modelled
- ✓ Also backwater effects from downstream rivers, pressurized flow, …
- ✓ Simulation time 48h event: 0.003 seconds (gain ~ factor 10^5)

Modular framework

Volume calculation:
- Continuity equation

Gate level calculation:
- PLC



Water level calculation:
- Hypsometric curve
- Rating curve
- Direct H-H relationship

+ dynamic correcting using ANNs

Flow calculation:
- Fixed weir equations
- ANNs
- Fuzzy systems
- Storage-Flow (e.g. transfer functions)
- Abstractions (e.g. pumps, infiltration)
- State Dependent Parameter estimations
- ...

➔ **Combination of computational technologies in integrated modelling framework**

Core of the models: artificial intelligence

- River / Floodplain (red)
- Sewer (blue)
- Other (yellow)

Continuity equation
- Close water balance

PWL
- Flows
- Water levels

Linear reservoir

Transfer function
- Flows
- Rainfall runoff

Static / Dynamic
- Flows

ANN
- Flows
- Water levels
- Rating curves

ANFIS
- Flows river - floodplain

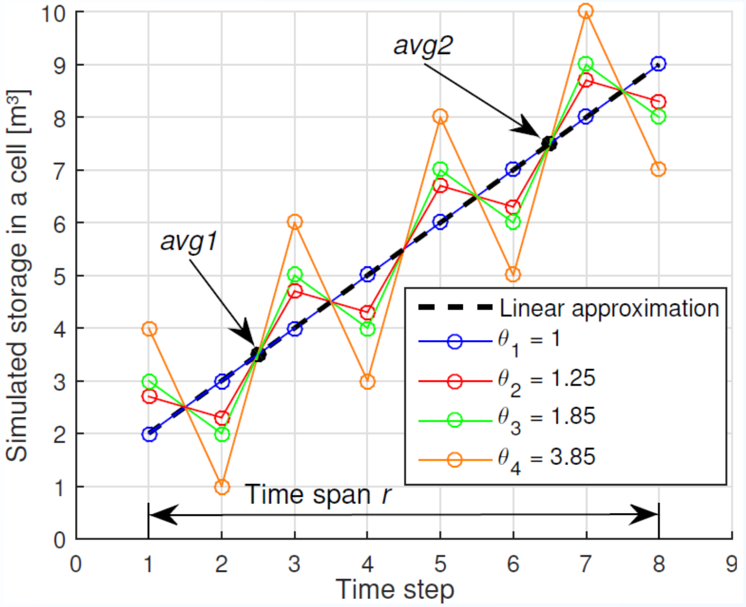
M5' trees
- Water levels
- Rating curves

SDP
- Rating curves

Hydraulic structures
- Flows

PLC
- Gate regulations

New and stable solver



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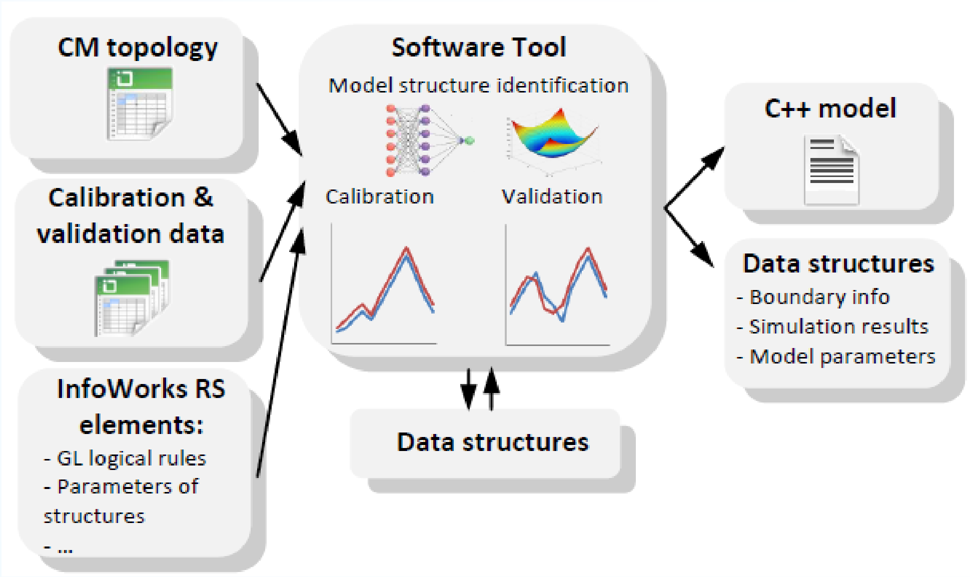
More info?

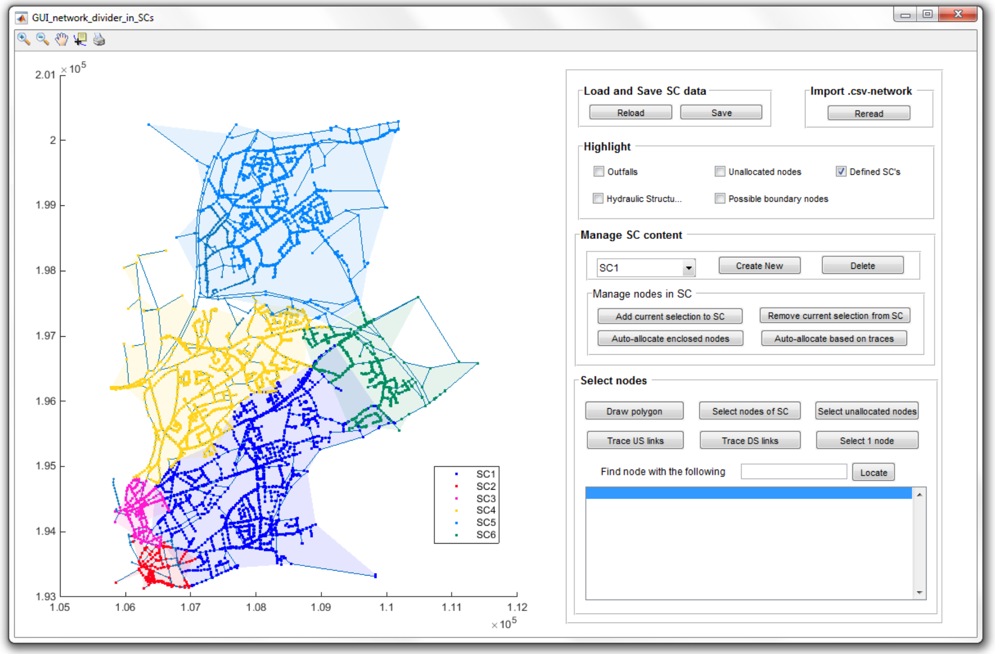
- Wolfs, Vincent, & Willems, Patrick. (2017). Modular Conceptual Modelling Approach and Software for Sewer Hydraulic Computations. *Water Resources Management, 31*(1), 283-298.
- Wolfs, Vincent, Meert, Pieter, & Willems, Patrick. (2015). Modular conceptual modelling approach and software for river hydraulic simulations. *Environmental Modelling and Software, 71*, 60-77.
- Wolfs, Vincent, Villazon, Mauricio Florencio, & Willems, Patrick. (2013). Development of a semi-automated model identification and calibration tool for conceptual modelling of sewer systems. *Water Science and Technology, 68*(1), 167-175.
- Meert, Pieter, Pereira, Fernando, & Willems, Patrick. (2018). Surrogate modeling-based calibration of hydrodynamic river model parameters. *Journal of Hydro-environment Research, 19*, 56-67.
- Meert, Pieter, Pereira, Fernando, & Willems, Patrick. (2016). Computationally efficient modelling of tidal rivers using conceptual reservoir-type models. *Environmental Modelling and Software, 77*, 19-31.

Semi-automatic model configuration

- Semi-automatic calibration and identification tool:
  - Data extraction and organization
  - Assists during model configuration
  - Model assembly

- Created in MATLAB with GUIs





Short list of applications

- Uncertainty analyses:
  - Climate change scenarios
  - River flood probability mapping (e.g. Wolfs et al., 2012)
- Optimization questions:
  - Intelligent real-time control (e.g. Vermuyten et al., 2018)
  - Design of Sustainable Urban Drainage Systems: case “the intelligent green roof”
- Impact analyses:
  - Retention basins on river floods (e.g. Wolfs & Willems, 2015)
  - Up- versus downstream storage in coupled sewer-river models (e.g. De Vleeschauwer et al., 2014)
  - CSOs on the receiving river water quality (e.g. Keupers et al., 2015)

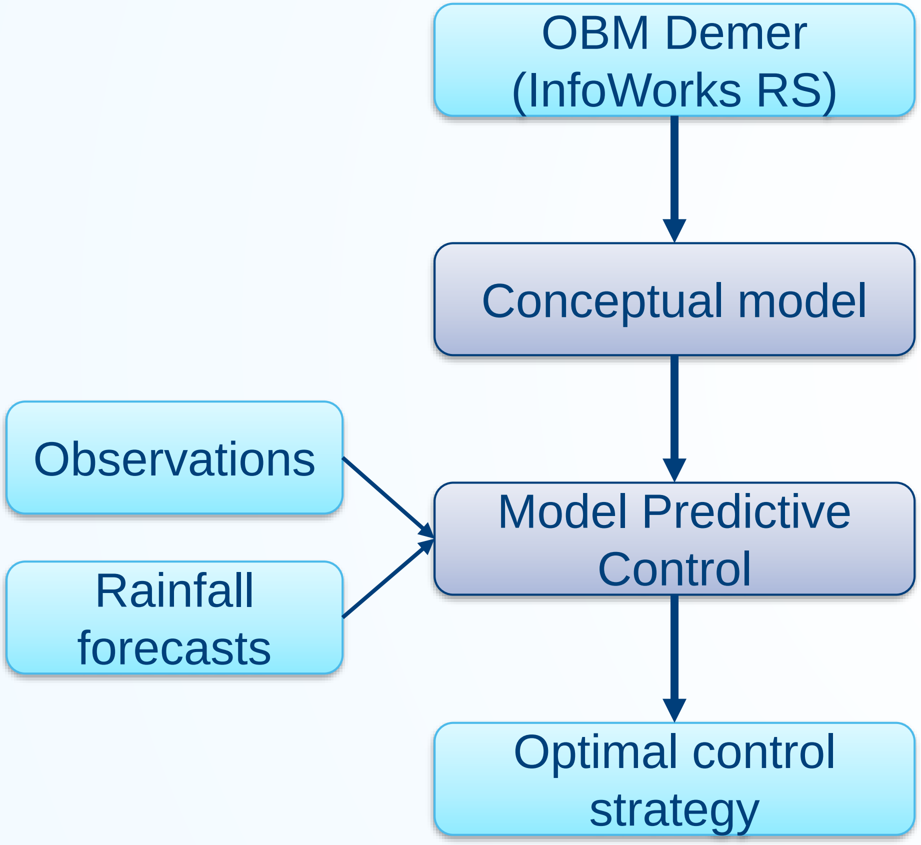
De Vleeschauwer, K., Weustenraad, J., Nolf, C., Wolfs, V., De Meulder, B., Shannon, K., Willems, P., 2014. Green-blue water in the city: quantification of impact of source control versus end-of-pipe solutions on sewers and river floods. Wat. Sci. Techn. 70 (11), 1825-1837.

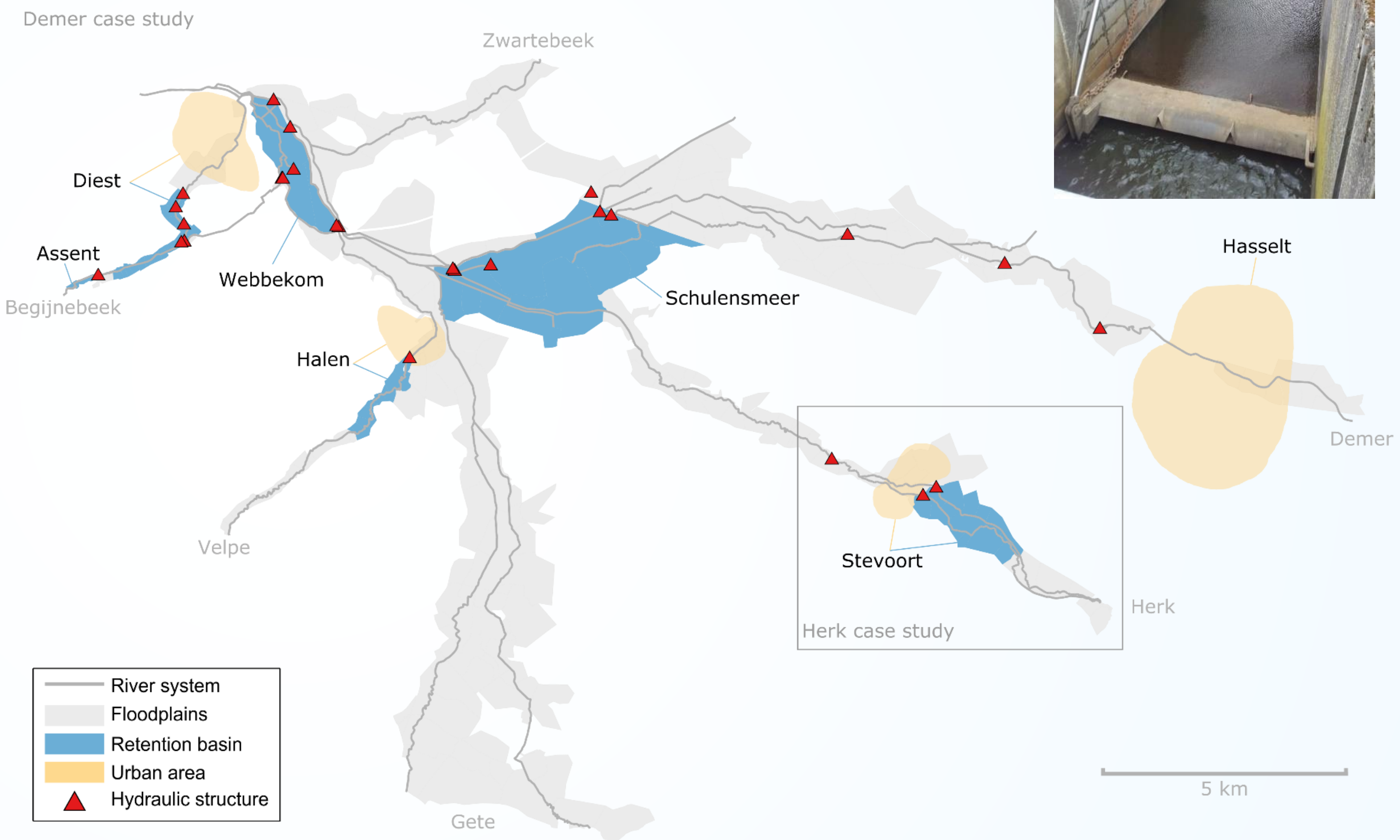
Keupers, I., Wolfs, V., Willems, P., 2015. Impact analysis of CSOs on the receiving river water quality using an integrated conceptual model. Submitted to the 10th International Urban Drainage Modelling Conference, Québec, Canada. 20-23 September 2015.

Vermuyten, E, Meert, P, Wolfs, V, & Willems, P. (2018). Combining Model Predictive Control with a Reduced Genetic Algorithm for Real-Time Flood Control. Journal of Water Resources Planning and Management, 144(2), Journal of Water Resources Planning and Management; 2018; Vol. 144; iss. 2; pp.

Wolfs, V., Willems, P., 2015. Quantification of impact of retention basins on river floods in the Dender catchment in Belgium using computationally efficient models. Proceedings of the 36th IAHR World Congress, The Hague, the Netherlands. 28 June – 3 July 2015.

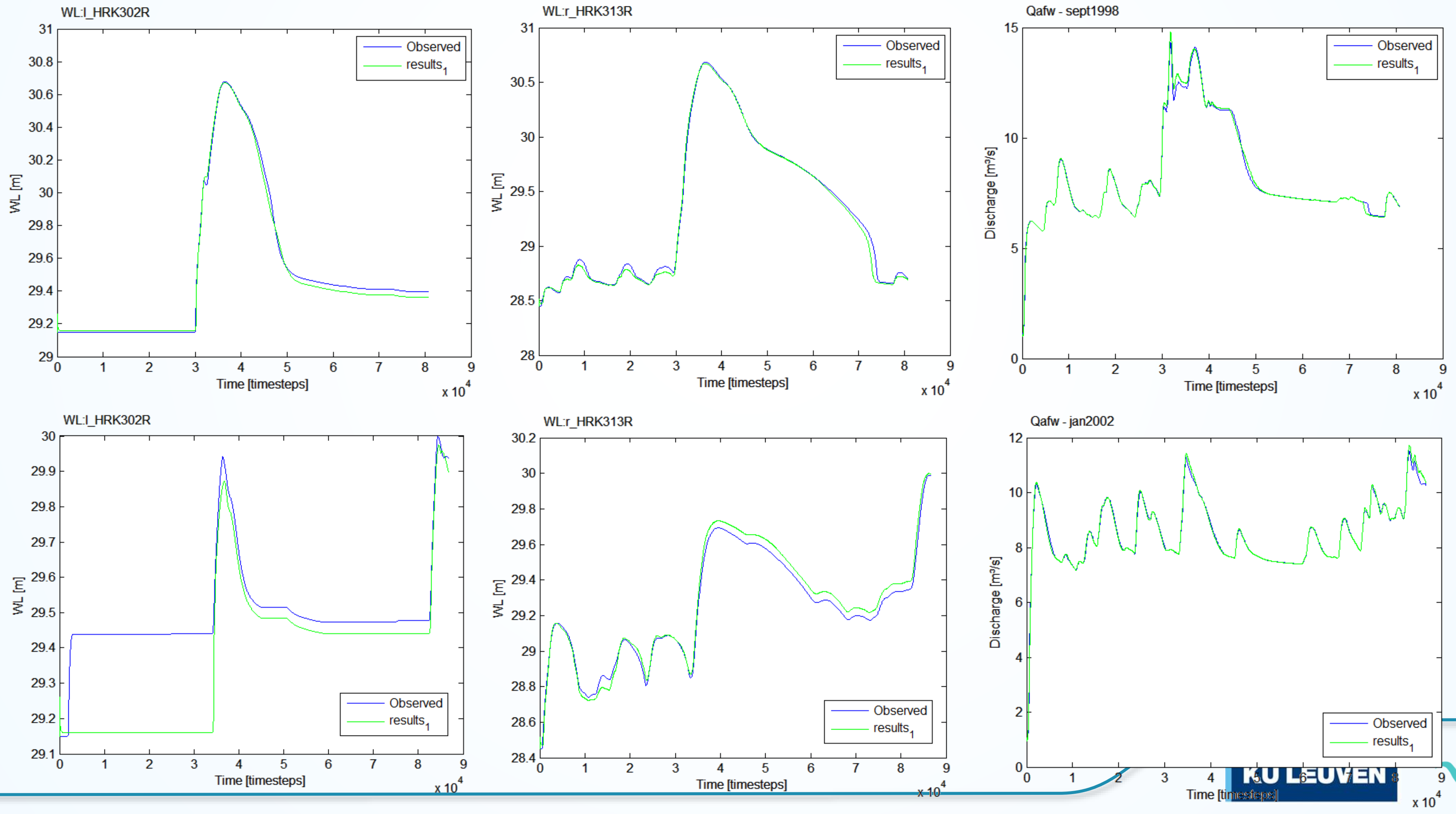
Example 1: RTC of the Demer basin





Example: RTC Demer basin

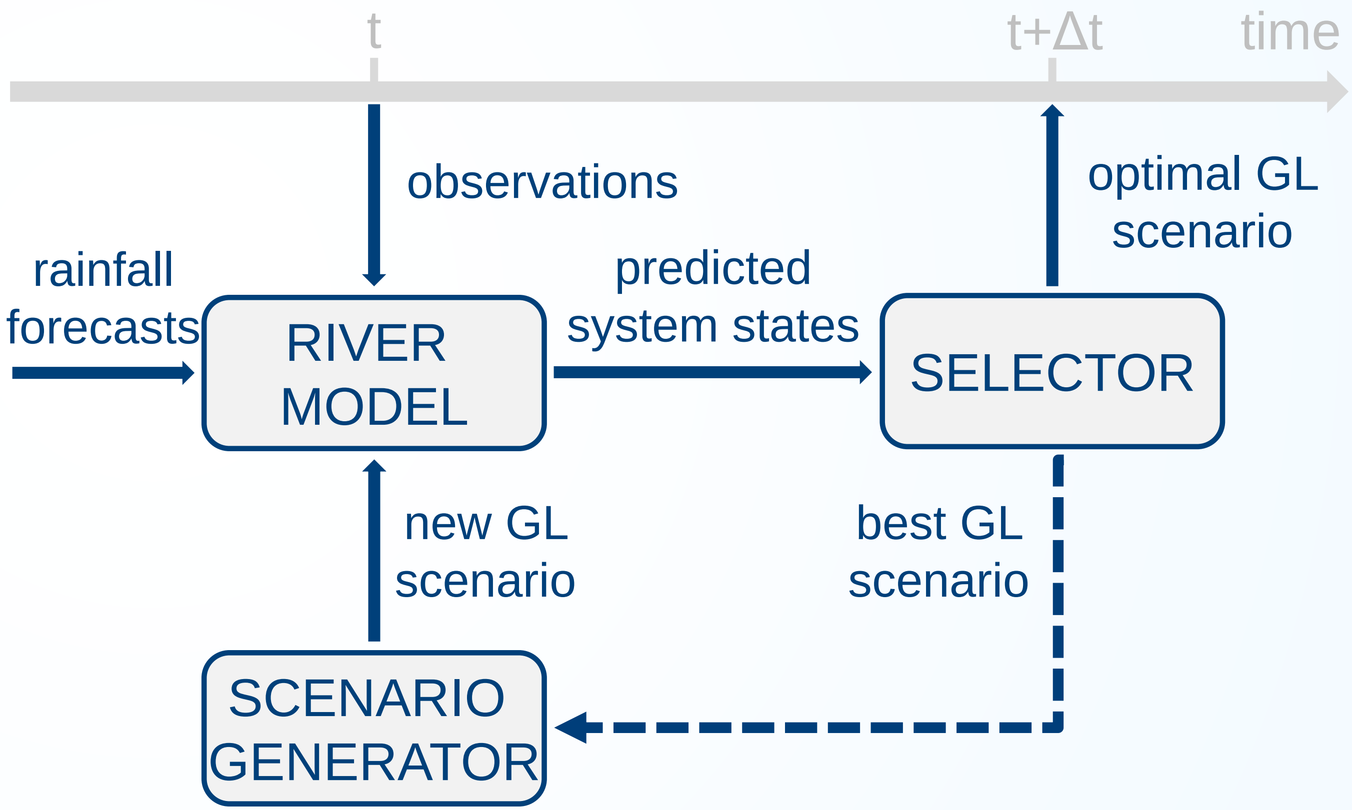
- Conceptual model results



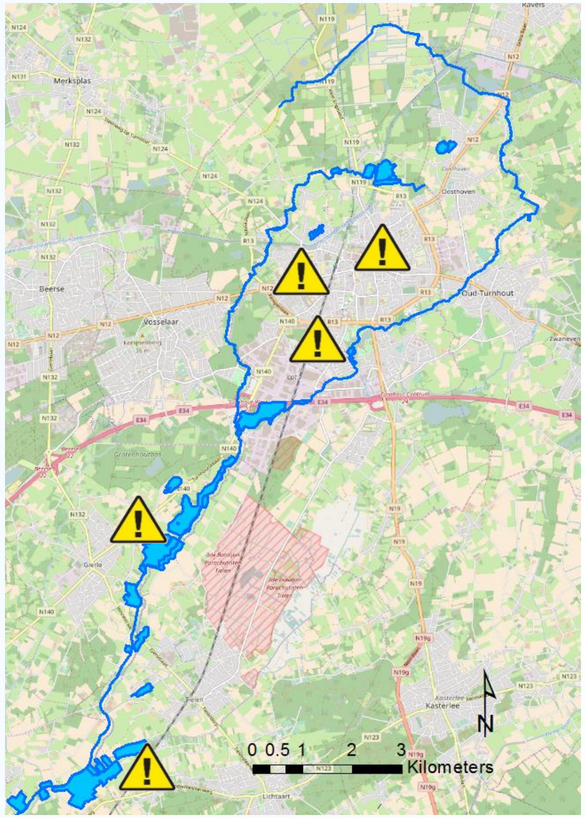
Example: RTC Demer basin

- Model Predictive Control
  - River model
  - Optimizer

- Reduced Genetic Algorithm
  - Based on standard GA
  - Objectives:
    - Retention basin dikes
    - Damage cost
    - Critical dikes
    - Retention basins

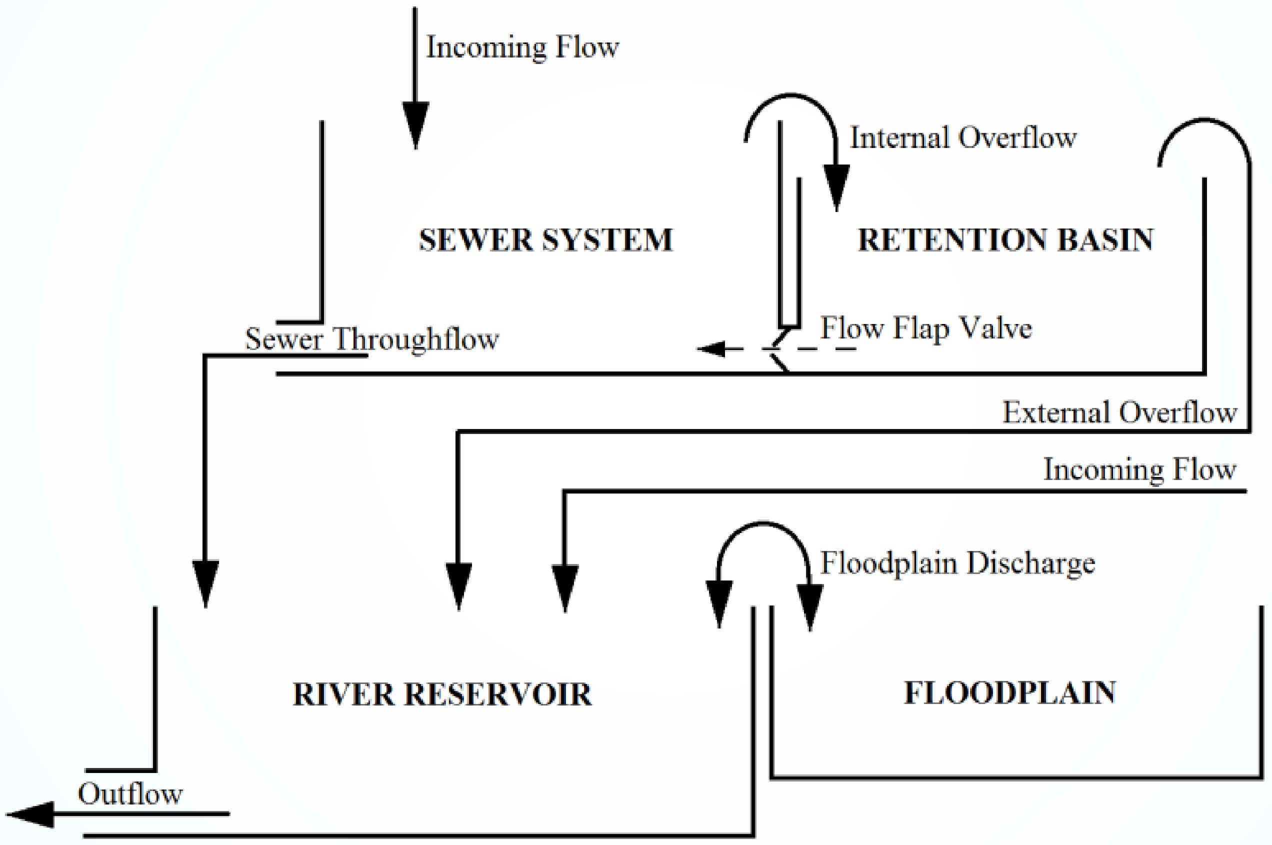


Example 2: SUDS to mitigate urban floods



- Heavy rain:
  - Floods in the city center
  - Floods along two nearby rivers
- Measures to reduce floods:
  1. Green zones (center)
  2. Buffers (at CSOs)
  3. Controllable floodplains
- Approach:
  - 100-year time series of rainfall data
  - Conceptual models (coupled)
  - Statistical post-processing of the results
- Interactions/timing sewer-river is complex and case specific

Example 2: SUDS to mitigate urban floods



Sirio: basic conceptual models with long term simulations

- ✓ Software to design SUDS
- ✓ Concept = long term simulations (100 years) + statistical analysis
- ✓ Standard tool in Flanders for rainwater design

Summary

- Integrated water management and applications (DSS, warning systems, real time control) require (1) fast, (2) flexible and (3) accurate models

  ➔ "Conceptual" models

- Newly developed approach: modular + Artificial Intelligence

- Enable various applications, examples Real Time Control (RTC), Sustainable Urban Drainage Systems (SUDS), scenario analyses and strategic planning (e.g. green roofs)

- Sirio: tool to simulate conceptual models using long term simulations

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