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# Development of a semi-automated model identification and calibration tool for conceptual modelling of sewer systems

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# Introduction

- Short computation time is often essential
- Current methods:
  - Physically based: de Saint-Venant equations
  - Conceptual: eg. Unit Hydrograph method, Muskingum routing

- Aim: development of a modelling approach which:
  - delivers accurate results for all types of flow
  - has very limited calculation times
  - allows for semi-automatic model structure identification and calibration
- Investigate:
  - Lumped conceptual modelling approach
  - Strong physical background
  - Calculate throughflow and overflow discharges

# Outline



- Model presentation
  - Concept of the modelling approach
  - Characterisation of a sewer system
  - Transfer Function (TF) models
  - Automation of model structure identification and calibration
- Case Study
- Results
- Conclusions

# Modelling approach

- Reservoir model
  - INFLOW: rainfall runoff, upstream systems, DWF, …
  - OUTFLOW: throughflow and overflow
- Calibration and validation data: simulation results of a detailed hydrodynamic model (ic. InfoWorks CS)
- Research is limited to the hydraulic aspects

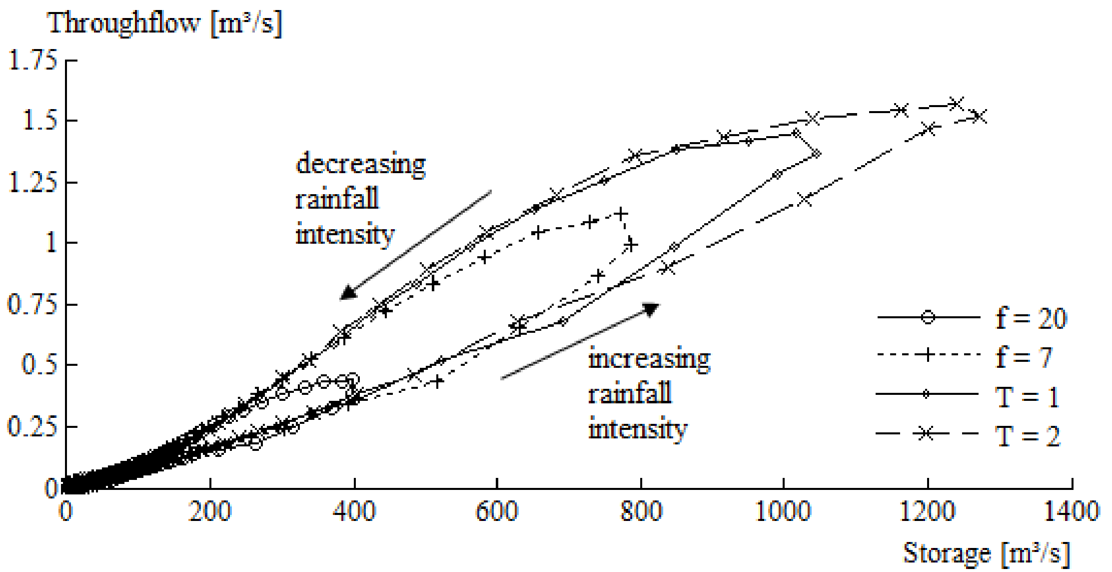
# Sewer system characterisation (1)

a. Concentration time:

- Smoothing of the inflow hydrograph
- Done by averaging the runoff over the concentration time
- Approximated (constant) as the center of gravity difference between the rainfall input and total outgoing flow

b. Storage/throughflow-relationships:

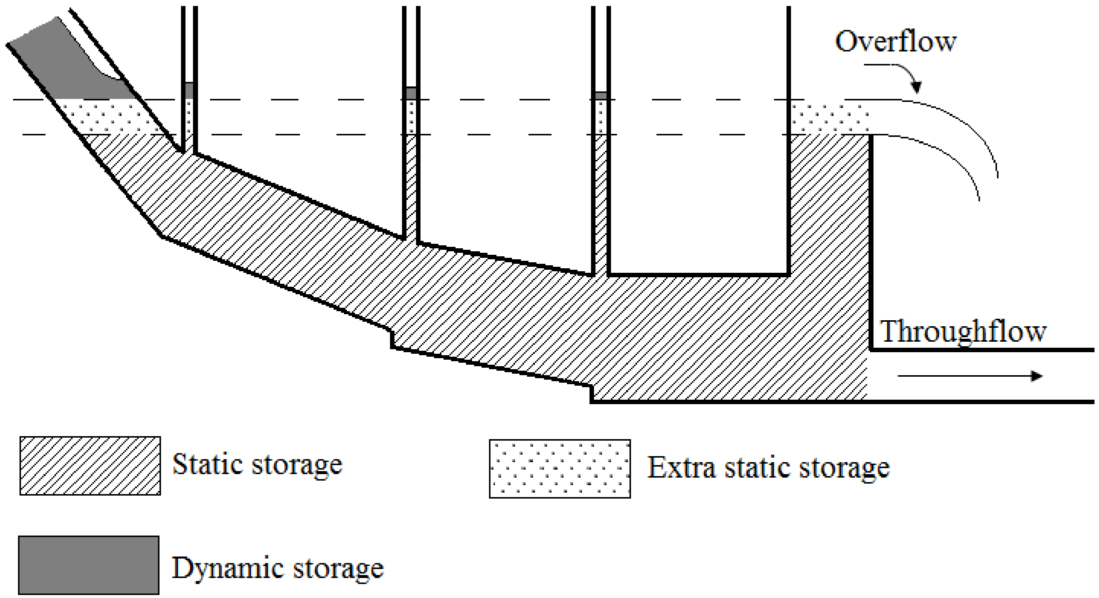
- Illustration: InfoWorks CS simulation results of a small fictitious gravity sewer system



# Sewer system characterisation (2)

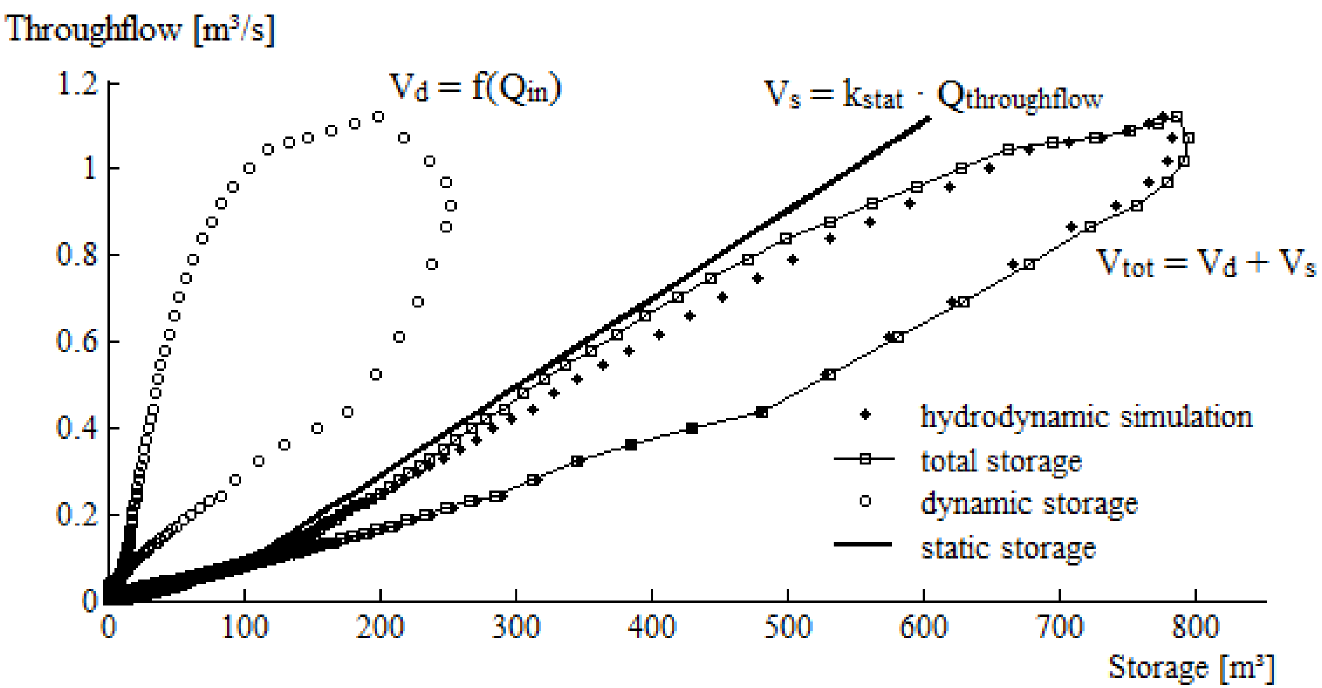


- Approach: division of storage in several artificial components (Vaes, 1999):
  - Static storage
  - Dynamic storage
  - Extra static storage during overflow



# Sewer system characterisation (3)

- Static storage: related to the throughflow
- Dynamic storage: related to the incoming flow

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# Transfer Function (TF) model (1)

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- Use of TF's:
  - flexibility
  - suitable for semi-automatic model structure identification and calibration
- Chow (1988), Beven (2001):

$$Q_t = \frac{b_0 + b_1 z^{-1} + \ldots + b_m z^{-m}}{1 - a_1 z^{-1} - \ldots - a_n z^{-n}} z^{-\delta} I_t \qquad \text{with} \quad z^{-1}Q_t = Q_{t-1} \qquad \text{(eq. 1)}$$

- $S_t = S_{dyn,t} + S_{stat,t}$ (eq. 2)

$S_{dyn,t} = r_d \cdot I_t$ (eq. 3)

$S_{stat,t} = r_s \cdot Q_t$ (eq. 4)

\+ continuity equation ⇒

$$Q_t \cdot \left(1 - \left(1 - \frac{\Delta t}{r_s}\right) \cdot z^{-1}\right) = I_t \cdot \left(-\frac{r_d}{r_s} + \left(\frac{r_d + \Delta t}{r_s}\right) \cdot z^{-1}\right) \qquad \text{(eq. 5)}$$

# Transfer Function (TF) model (2)

- More complex relationships for $S_{stat}$ en $S_{dyn}$ possible:
  - Dependence on different time steps: eg. $S_{dyn} \sim I_t$ and $I_{t-1}$
  - Piecewise linear relationships
- Several approaches:
  1. Analytical solution (eq. 5) → "CM method 1"
  2. Uncoupled static and dynamic volume → "CM method 2":
     - Static Volume ~ Outflow (piecewise linear relationships)
     - Dynamic Volume = an arrangement of linear reservoirs depending on the incoming flow (TF)

# Automation

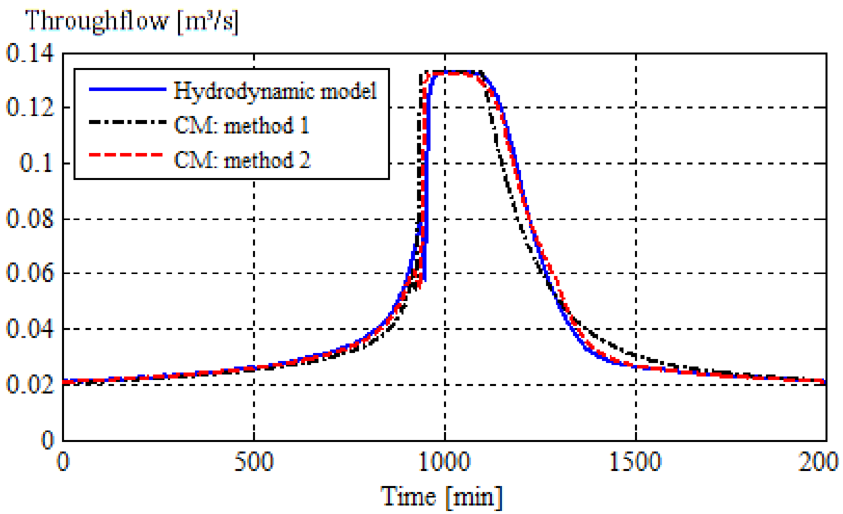
- MATLAB/Simulink® tool with GUI
- Inputs: simulation results (incoming flow, throughflow and overflow) and timestep
- TF calibration by means of the Captain Toolbox (Young et al., 2007):
  - Identification: Cross-correlation function (Box and Jenkins, 1970) and various statistical criteria such as YIC (Young, 1984).
  - Parameter estimation: Refined Instrumental Variable (Pedregal, 2007).
- Self chosen values of $r_s$ and $r_d$ (cf. eq. 3 and 4)

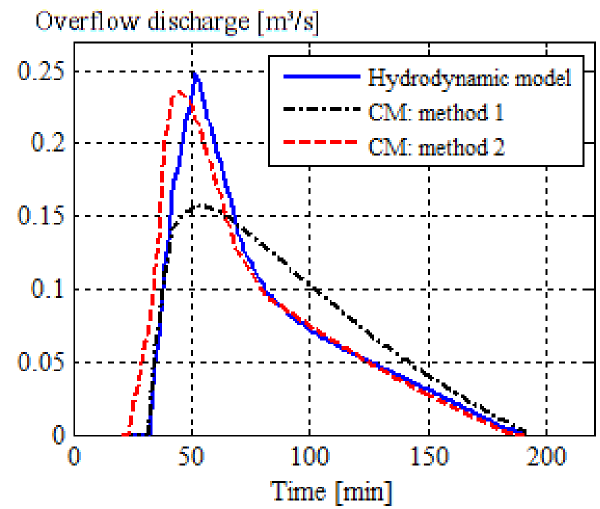
# Case Study

- Sewer system of the city of Geel, Grote Nete Catchment, Flanders, Belgium.
- Detailed InfoWorks CS (IWCS) model (provided by the water company Aquafin)
- Characteristics of the considered subsystem:
  - Reduced area of 12.33 ha
  - Population equivalent of 430
  - 3 CSO's
- Rainfall used for simulations in IWCS:
  - Composite storms with frequencies ranging from 20 ('f20') to 1 ('f1') per year, and return periods from 2 ('T2') to 20 years ('T20') with a timestep of 10 minutes and duration of 48 hours.
  - Long term time series of rainfall measurements from 13 sept. 2001 – 11 jan. 2010 with a 15-minute timestep.

# Results: composite storms

- Hydrographs of the throughflow and cumulated CSO discharges for the composite storm T2

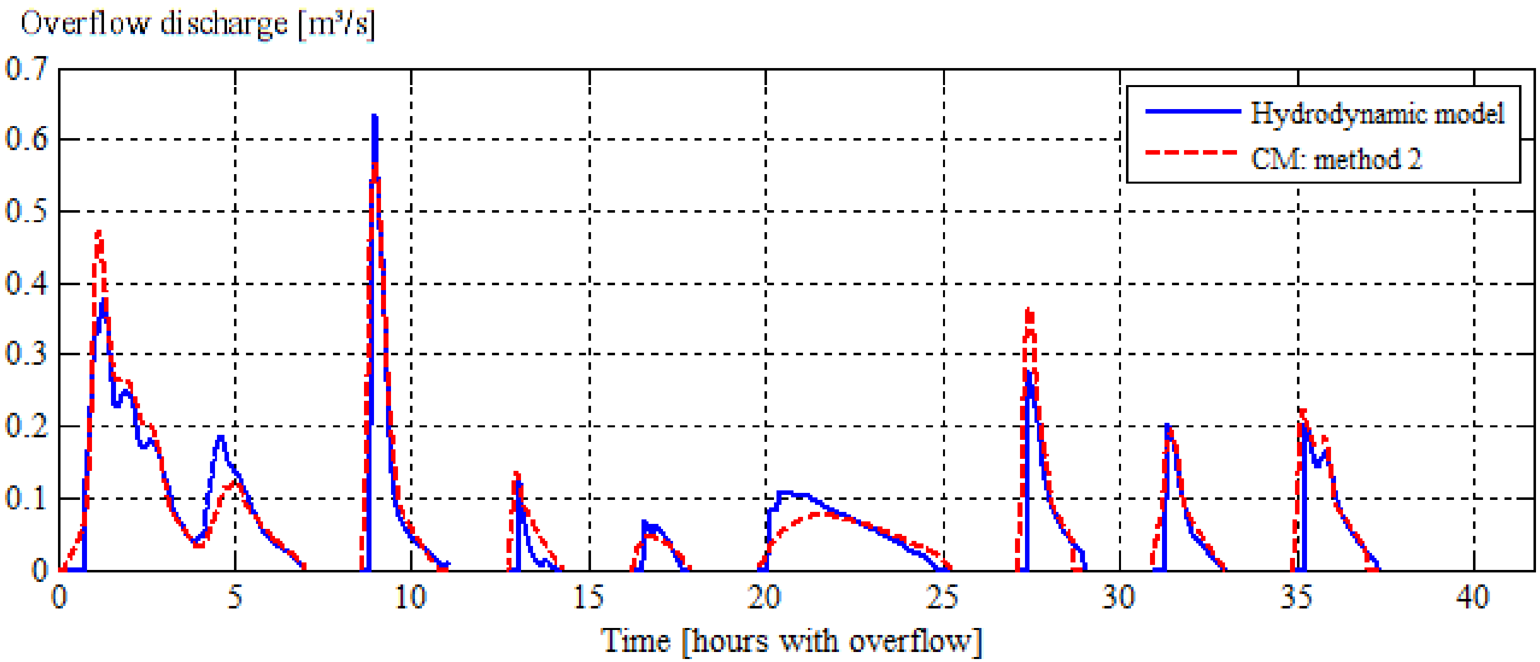



| *(NSE values)* | | f20 | f10 | f7 | f1 | T2 | T5 | T10 | T20 |
|---|---|---|---|---|---|---|---|---|---|
| Throughflow | CM1 | 0.91 | 0.96 | 0.96 | 0.97 | 0.95 | 0.93 | 0.93 | 0.92 |
| | CM2 | 0.97 | 0.98 | 0.99 | 0.99 | 0.98 | 0.97 | 0.97 | 0.95 |
| Cumulated CSO discharge | CM1 | n.a. | n.a. | n.a. | 0.86 | 0.92 | 0.77 | 0.66 | 0.60 |
| | CM2 | n.a. | n.a. | n.a. | 0.78 | 0.94 | 0.96 | 0.97 | 0.97 |

# Results: long term simulation

- Long term simulation (8 years)




- Calculation time < 3 minutes (1 minute time step)

# Conclusions



- Current (conceptual) models:
  - Critical calculation time
  - Often lack accuracy in predicting (CSO) discharges
  - Calibration process is time-consuming
- Presented modelling approach:
  - Physical approach: division in several storage components
  - Use of Transfer Functions led to two methodologies
  - Calibration semi-automatic process
- Case study (InfoWorks CS model):
  - Composite storms and long term simulations used
  - Significant shorter calculation time
  - Accurate and stable results

# References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