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PUBLIC RESEARCH CENTRE HENRI TUDOR

Modelling and Optimal Control of a Sewer Network

C.1 Hydraulic application (6.9.2012)

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Overview

Case study

- The system that is analyzed and controlled

Modelling and calibration

- Use of different model types
- What are the models
- Model calibration & comparison

Model predictive control

- MPC Principals
- Objectives of MPC underlying optimization
- Results based on simulation

Implementation issues

Conclusions

The studied sewer system

Artificial Lake, mainly used for drinking water

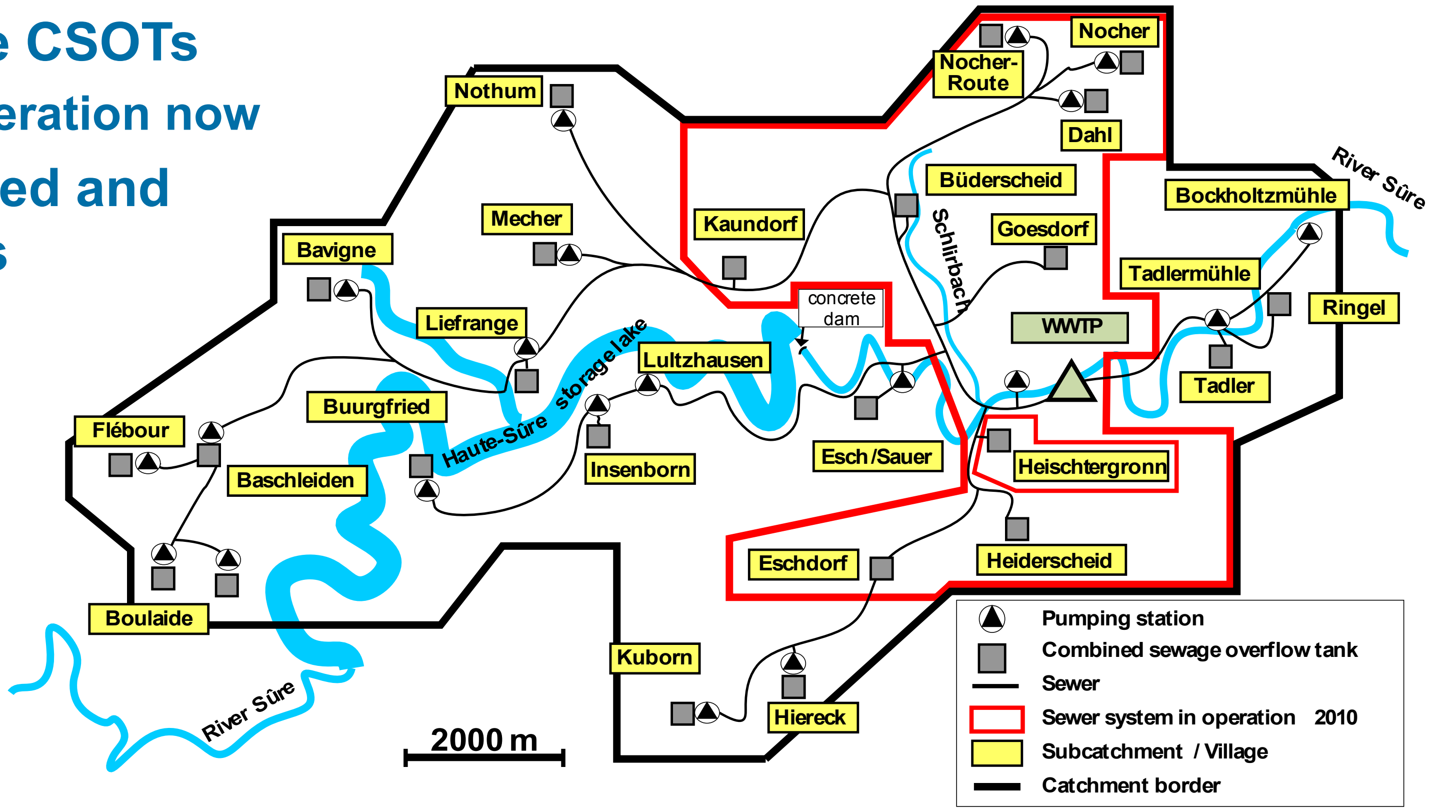
Combined sewer network to drain to central WWTP

24 controllable CSOTs

- 8 are in operation now

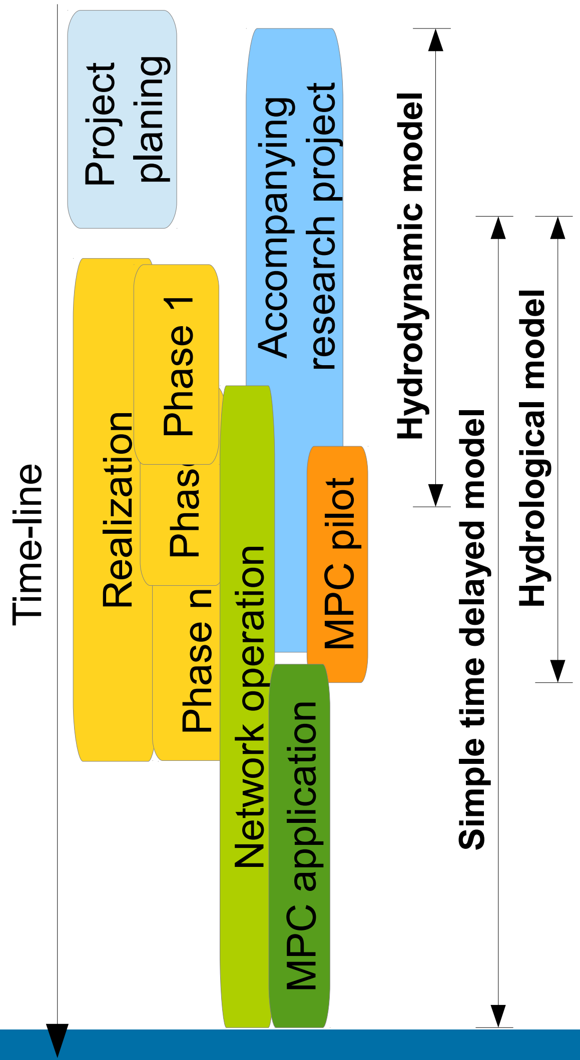
Mix of pressured and free flow pipes

Summer 2010	
Population equivalents	3869
Impervious surface	80 ha
CSOT	8
Total CSOT volume	1600 m^3
PS	4
Total transport sewer length	19.7 km
Pressure conduits	4.1 km



Modelling and calibration

Use of different model types



Hydrodynamic model

- Planing, case studies, network analysis
- In the context of the research project and the project planning
- Creates data for the calibration of the other models (offline virtual reality)

Simple time-delayed model

- Used inside to the model predictive control
- Implemented in Matlab for offline simulations and Python for the MPC pilot implementation

Hydrological model

- Used for long time simulations and as virtual reality for testing the MPC approach
- Integrated Control Sewer & WWTP (PhD)

Modelling and calibration

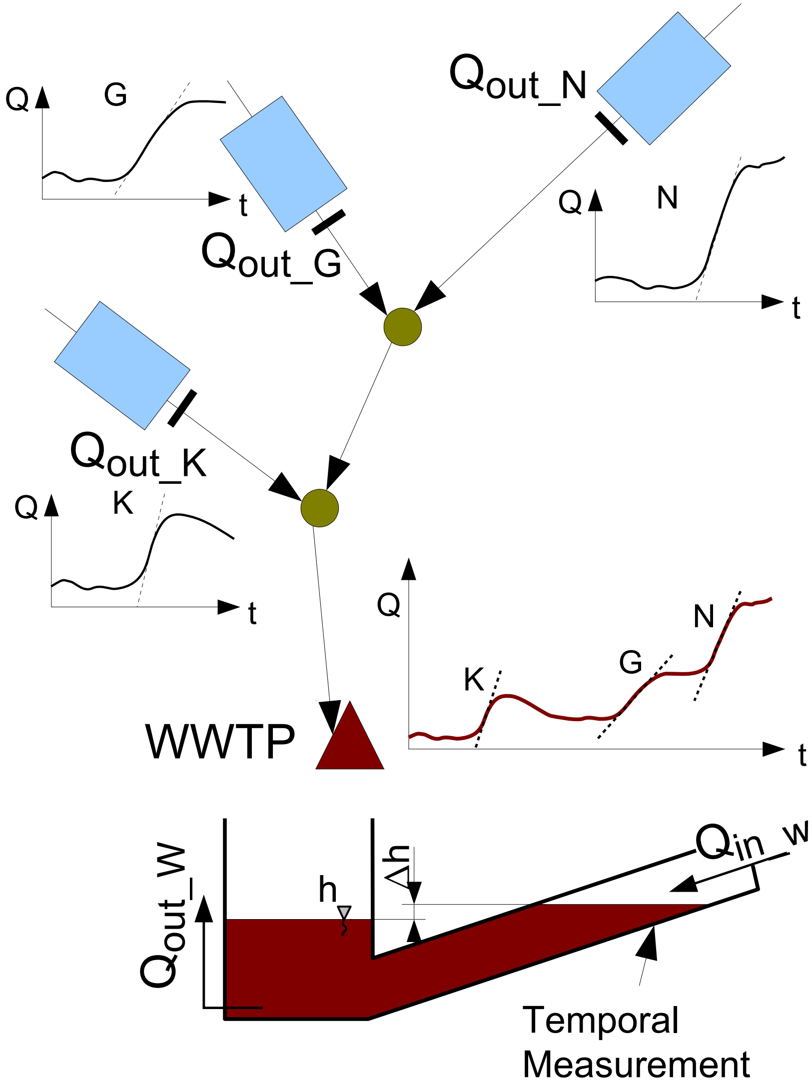
Flow time and profile test

Test design and properties

- dry weather situation
- Impounding of the dry weather flow in CSOTs
- Release of the throttled volumes in a given temporal sequence for each CSOT

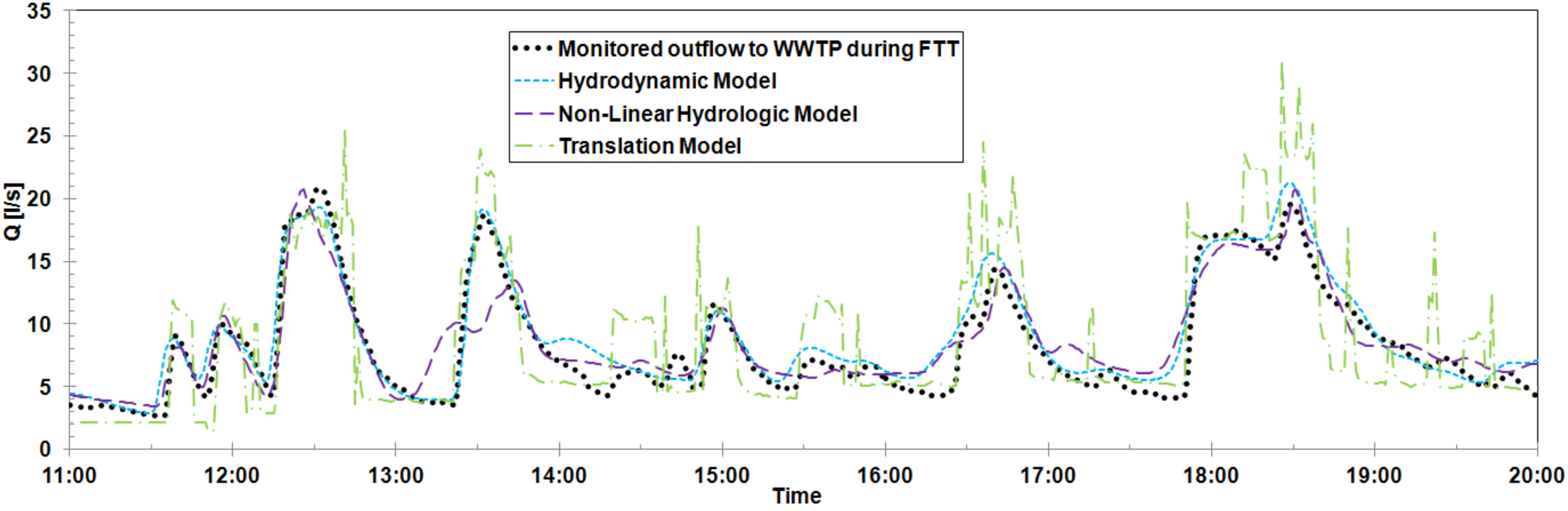
Test goal

- Allocation of the Qin_{WWTP} pattern to $Qout_{CSOT,i}$
- identification of individual flow times from each CSOT to the WWTP
- Validation of the hydrodynamic model
- Evaluation of the other models



Modelling and calibration

Result and discussion



- Hydrodynamic model fits quite good to the monitored flows
- NL hydrological model much less detailed compared to the HD-Model but is able to reproduced most of the dynamics.
- Translation Model gets the timing of of the waves good enough for the use in the MPC context.

Model predictive control

used principals

System

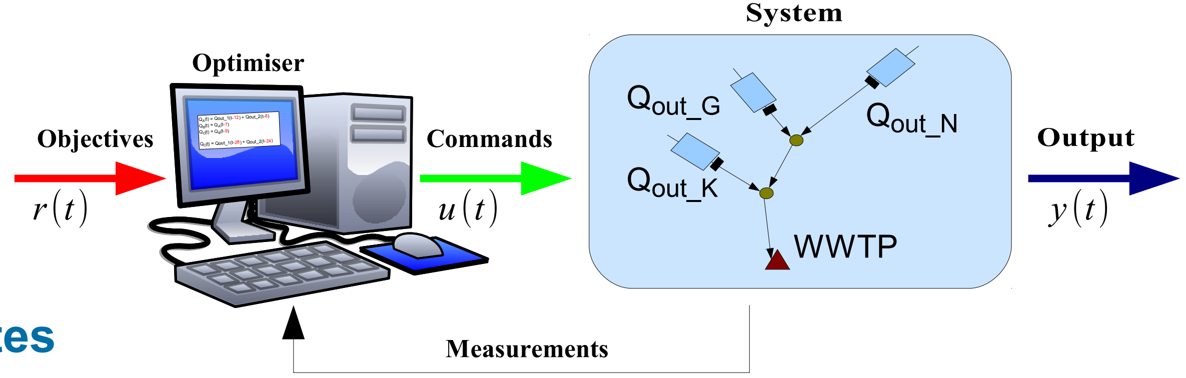
- Measurements
- Historic data
- Controllable aggregates

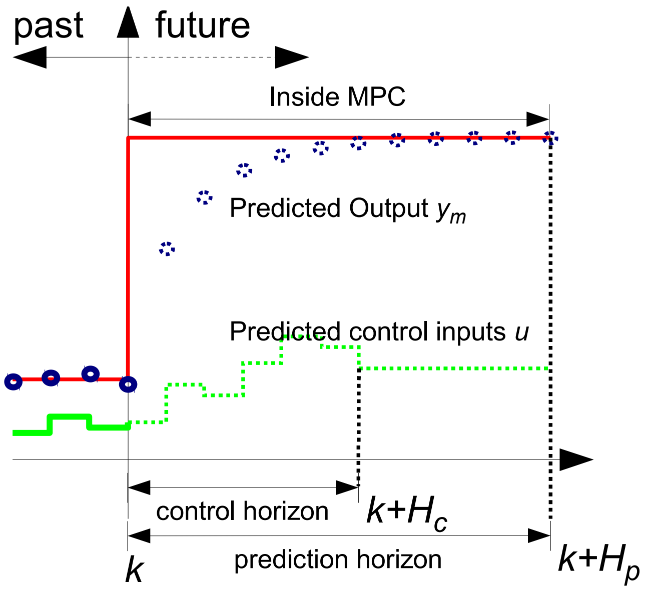
Optimizer

- Input forecasting
- Model based output prediction
- Objective-function
- Optimization over prediction horizon

Control loop

- Apply control for u(k+1)
- Run the optimization in real time (Δt)
- Update to current system state





Model predictive control

for the proposed sewer systems

Multi-Objective function

$$\text{minimize} \quad J = \sum_{n=t}^{t+Hp} \lambda\varphi_1(n) + \beta\varphi_2(n) + \alpha\varphi_3(n)$$

$$\text{subject to} \quad c_i(x) = 0 \quad i \in E$$
$$c_i(x) \geq 0 \quad i \in I$$

- **Homogenous distribution of the storage**

$$\varphi_1(n) = \sum_{i=1}^{N}\left[V_i(n) - \frac{V_i\max}{\sum_{i=1}^{N} V_i\max}\sum_{i=1}^{N} V_i(n)\right]^2$$

- **Constant inflow to the WWTP**

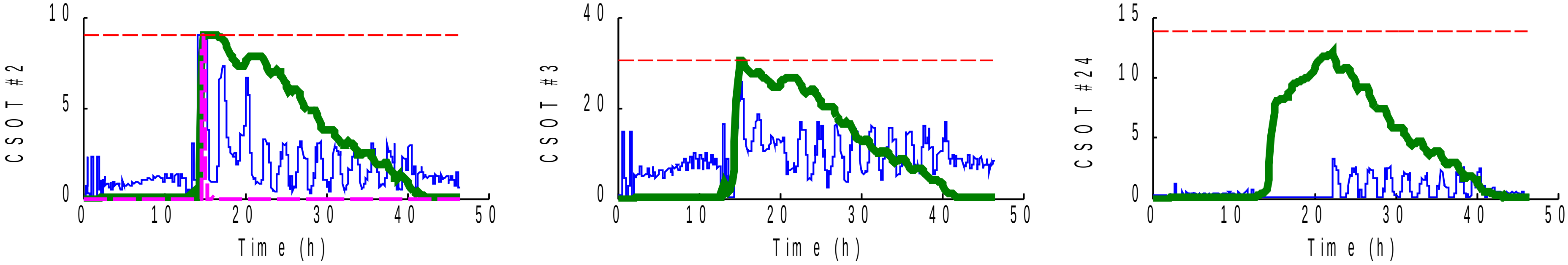
$$\varphi_2(n) = \left[y_{ref}(n) - \sum_{i=1}^{N^*} Out_i(n - d_i)\right]^2$$

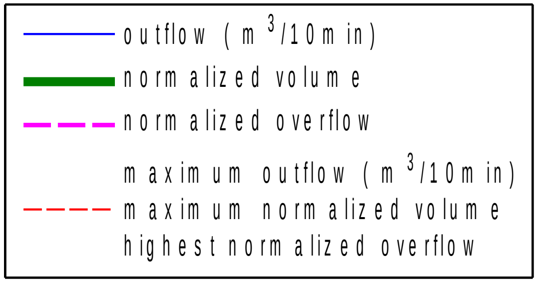
- **Minimum overflow**

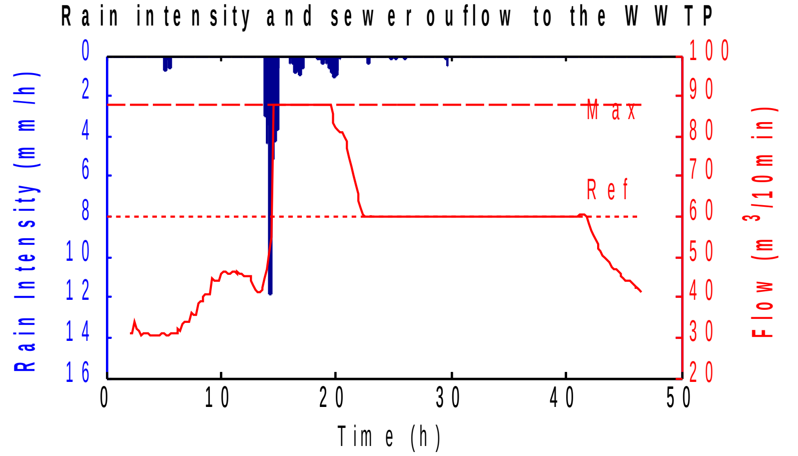
$$\varphi_3(n) = \sum_{i=1}^{N}\left[Ov_i(n) - NL\right]^2$$

Model predictive control

some results

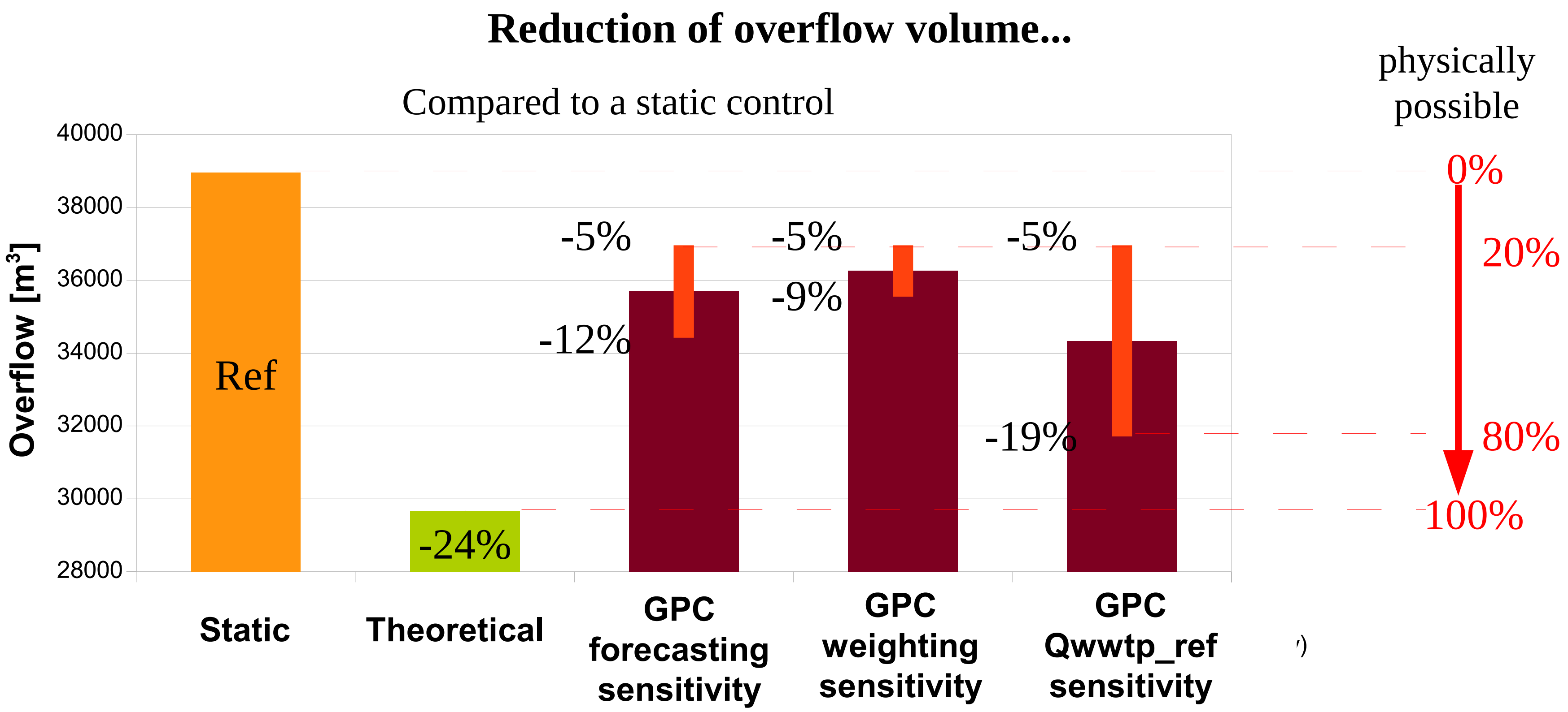




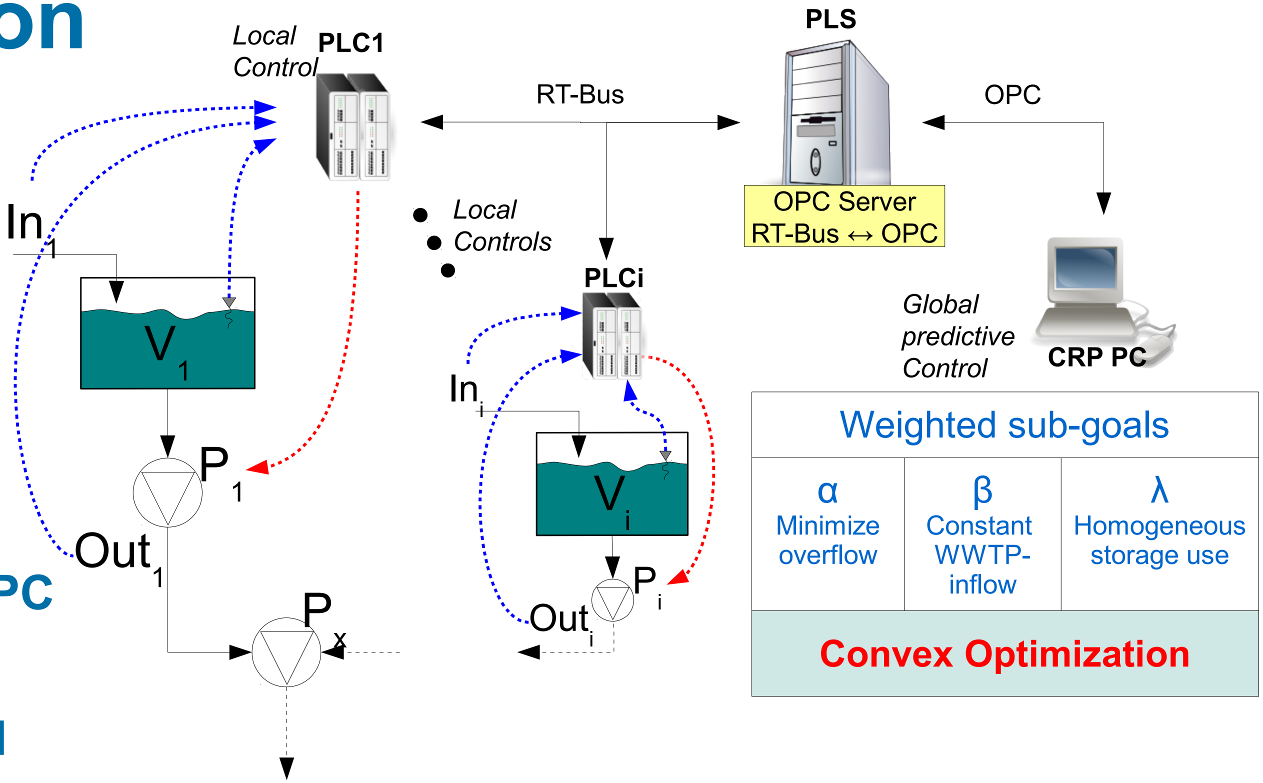


Model predictive control

some results



Implementation



Weighted sub-goals		
α Minimize overflow	β Constant WWTP-inflow	λ Homogeneous storage use
Convex Optimization		

PLS – SCADA

- centralize all network variables
- Via real time bus
- User and Admin interface for the GPC

OPC interface

- Industrial standard
- Exists for most SCADA hardware
- Software libraries available in FOSS

Global Predictive Control implementation

- Matlab → Python
- End-User system feedback / training / issues
- Fall-back strategies

Conclusions

Different models used in different phases of the project

Virtual reality

- important to demonstrate the possible gains of the GPC approach
- important to analyze different control approaches
- validate the effective gains of the controlled system after implementation

Simple sewer model (time delayed / plug flow)

- linear, robust model
- calibration towards the real network affordable
- convex optimization

Further works

- Integrate a global quality component in the simple model
- Handling structural network modifications in the GPC approach