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Integrated Control of Sewer Network and WWTP using the Example of Small Rural Municipal Systems

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Novatech2013, Lyon, June 23 2013

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Outline

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Control of wastewater systems
Conventional Wastewater Treatment Plants

- Processes

Preliminary and primary treatment → Secondary treatment → Tertiary treatment

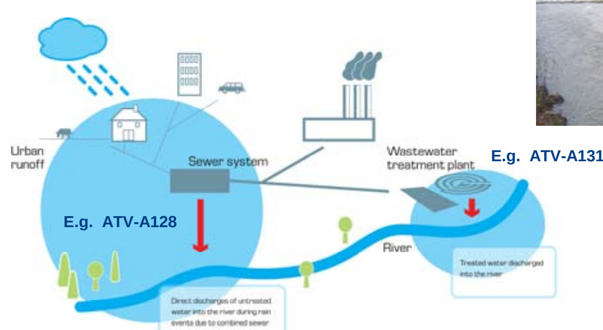
- **Screening**
- **Primary clarifiers**

- **Bioreactors**
- **Secondary clarifiers**
- **N/P-removal**

- **Filtering**
- **Chlorination**
- **UV-treatment**
- **…**

- Real-time control
  - Primarily for the secondary treatment
    - Controllers
      - e.g. PID, Fuzzy, …
        - Aeration
        - Precipitation
        - Sludge control, etc.
    - Goals:
      - Cost savings (aeration)
      - Process improvement

Control of wastewater systems
Integrated control



Source: Anne-Marie Solvi, Modelling the sewer-treatment-urban river system in view of the EU Water Framework Directive, PhD, Ghent University, 2006

- Control of the subsystems sewer network (SN) and wastewater treatment plant (WWTP) according to:
  - States
  - Capacities

Control of wastewater systems
Integrated control

- Basis
  - Availability of information regarding
    - States
    - Capacities
  - Subsystems
    - Catchment
    - SN
    - WWTP
    - Receiving water
  - Central process control unit

Control of wastewater systems
Integrated control

- Decision making
  - Example
    - Dynamic control of the inflow to the WWTP according to:
      - Hydraulic capacities
      - Nutrient removal capacities

        → Increase of capacities in the SN

        → CSO reduction leading to a relief of the receiving water

Constraints and requirements
Process dynamics

Submodel	Process	Dynamics	
Catchment	Pollution accumulation	Slow	Days
	Runoff formation	Fast	Minutes – hours
	Pollution wash off	Fast	Minutes – hours
Retention Tank	Filling	Fast	Minutes - hours
	Emptying	Slow	Hours – days
Trunk sewer	Translation & retention	Medium	Minutes – hours
WWTP	Biology	Fast - Medium	Minutes – hours
	Aeration	Fast	Minutes
	Sedimentation	Fast	Minutes
	Hydraulics	Fast	Minutes
	Activated sludge household	Slow	Days

Constraints and requirements
Software

- Requirements
  - Simulation models
    - Hydraulic models (translation and / or retention)
    - Quality models
      - SN: Pollution load models (e.g. accumulation and wash-off)
      - WWTP: Activated sludge models (e.g IWA ASM1 – 3)
      - RW: Water quality models (e.g. IWA RWQM1)
  - Control models
    - Computational demand
    - Robustness
  - Integration of submodels
    - Continuity
      - Translation of process variables
    - Information availability
      - Processes
      - Disturbancies (e.g. Kalman- Filters)
  - Implementability of control strategies

Constraints and requirements
Sensors and actuators

- Sensors

Subsystem	Sensor	Objective
Sewer / CSOT	Rainfall	Discharge prediction
	Discharges	Discharge prediction
	Water level	Hydraulic capacity
	Concentrations	Load estimation
WWTP	Discharges	Hydraulic control
	Sludge level	Hydraulic capacity estimation / control
	Concentrations	Process monitoring

Methodolgy
Sensors and actuators

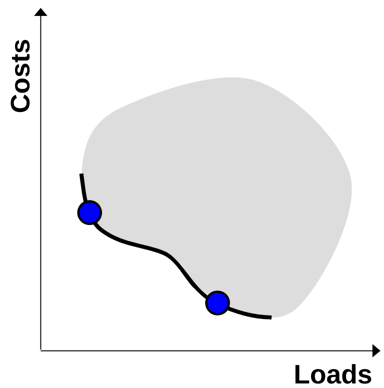
- Actuators

Subsystem	Actuators	Objective
Sewer / CSOT	Pumps, throttles	Discharge control
WWTP	Pumps (wastewater)	Discharge control
	Pumps (sludge)	Process control
	Pumps (chemicals)	Process control
	Blowers	Process control

Constraints and requirements
Decision making

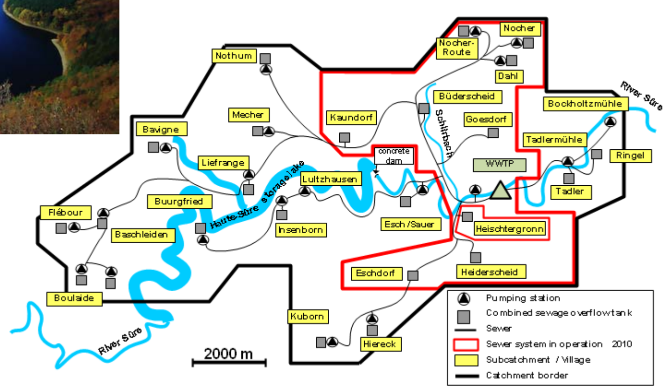
- Optimization is decision making
  - Often conflicting objectives
    - E.g. treatment degree vs. treatment costs
    - Several pareto optimal solutions

      →Weighting of interests
      - **Pre-weighting**
        - **1 result → practicable**
      - Post-weighting
        - Pareto front



Case study ReseauSure
Overview

Summer 2010	
Population equivalents	3869
Impervious surface	80 ha
CSOT	8
Total CSOT volume	1600 m³
PS	4
Total transport sewer length	19.7 km
Pressure conduits	4.1 km



Case study ReseauSure
Overview

Characteristics of the catchment

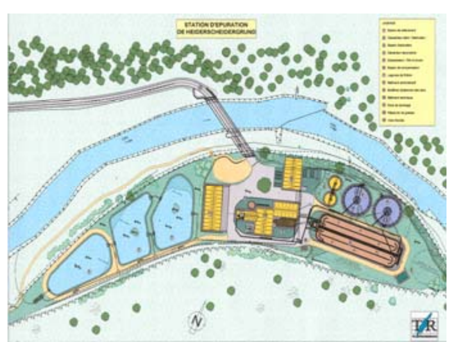
	Final	2012	Range
Villages	34	9	
Population equivalents	12000	3869	165 – 611
Impervious surface	200 ha	80 ha	4.2 – 13.6 ha
Trunk sewer network (combined system)	60 km	19.7 km	
CSO structures	23	9	
Retention tanks volume	3000 m^3	1600 m^3	90 – 330 m^3
Throttle flows			4 – 10 l/s
Pumping stations	25	6	
Pressure conduits	39.3 km	4.1 km	

Case study ReseauSure
Overview

Characteristics WWTP Heiderscheidergrund

	Final	2012
DWF	2225 m^3/d	500 - 600 m^3/d
Max RWF		150 - 200 m^3/h

- Oxidation ditch with intermittent aeration
- Simultaneous aerobic sludge stabilisition
- Chemical P-removal
- 2 lanes for summer / 1 lane for winter operation
  - 2 * 2770 m^3



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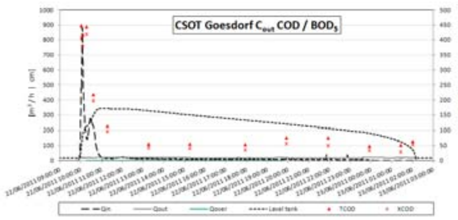
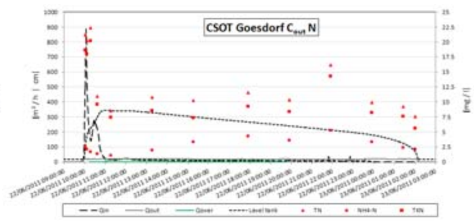
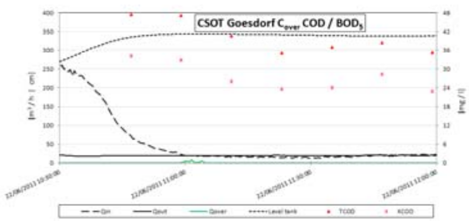
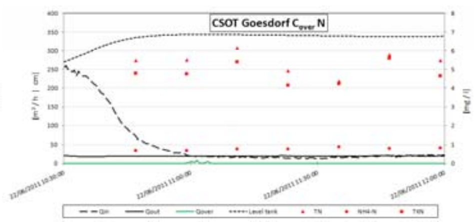
Overview

- Pollutographs RWF (examples)









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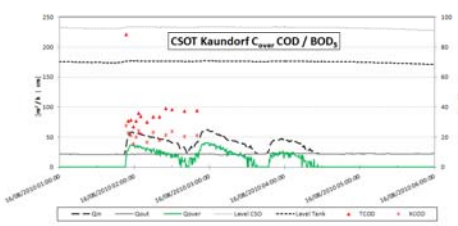
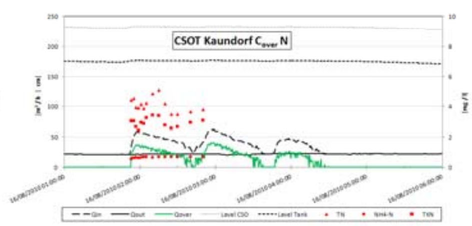
Overview

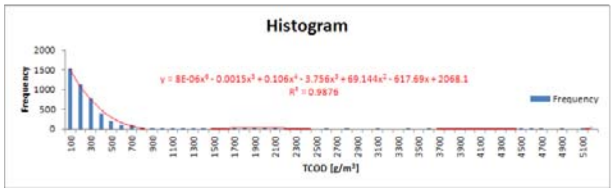
- Pollutographs RWF (examples)





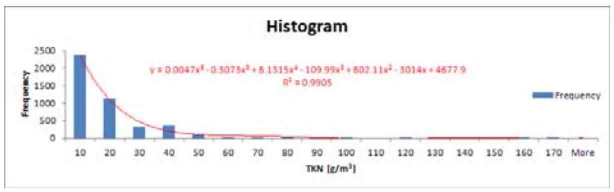
Case study ReseauSure
Overview

- Summary MWF concentrations
  - TCOD



	TCOD [g/m3]
MIN	35.2
Q1	75.33
AVERAGE	244.8
MEDIAN	144.2
Q3	291
MAX	5089.9

  - TKN



	TKN [g/m3]
MIN	3.72
Q1	7.71
AVERAGE	15.74
MEDIAN	9.38
Q3	16.44
MAX	161.04

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Sensitivities

- Filling rate of CSOTs
  - Min: 10 min
    → $H_{C,SN}$ = 10 min
- Transport time from CSOTs to WWTP
  - Average: 58 min
  - Std: 12 min
    → $H_{P,SN}$ = 2 h
- Duration of dry weather flow periods (June 2010 – Jan 2013)
  - Average: 3.08 d
  - Std: 2.54

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Overview

- WWTP Heiderscheidergrund: Legal effluent limits

Parameter	Limit	Condition
TS	< 30 mg/l < 30 mg/l	24 h mixed sample 2 h mixed sample
BOD_5	< 15 mg/l O_2 < 20 mg/l O_2	24 h mixed sample 2 h mixed sample
TCOD	< 75 mg/l O_2 < 90 mg/l O_2	24 h mixed sample 2 h mixed sample
NH_4-N	< 3 mg/l < 3 mg/l	24 h mixed sample 2 h mixed sample
TN	< 15 mg/l < 15 mg/l	24 h mixed sample 2 h mixed sample
TP	< 1 mg/l < 1 mg/l	24 h mixed sample 2 h mixed sample
pH	7 – 8.5	

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Methodology

- Objectives of the model predictive control (MPC) approach
  - WWTP
    - Maximization of the inflow during rain weather
      - $Q_{WWTP,in,max}$
      - While finding the optimum aerated volume $V_{N,opt}$
  - Sewer network
    - Maximization of the outflow to the WWTP according to
      - $Q_{SN,out,ref} = Q_{WWTP, in,max,}$
    - Priorization of overflow to the less sensitive receiving waters
      - Harmonization of water levels in the retention tanks according to receiving water categories 1 to 3

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Methodology

- Assumptions for the presented integrated control loop
  - WWTP
    - Good influent flow prediction for the next day
    - Online adaptation to the current state of the WWTP (e.g. Kalman Filter)
  - Sewer network
    - Good rainfall prediction for the next day
    - Transferability of the SN model calibration to the final state for a good WWTP inflow prediction
    - Online adaptation to measurement data according to prediction errors at each retention tank (e.g. Kalman Filters)

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Methodology

- Boundary conditions for the global optimization
  - WWTP
    - Stay below the legal effluent limits
  - Sewer network
    - Hydraulic capacities of
      - Sewer network
      - Pumps and throttles
      - (according to the existing network resp. design data)

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Methodology

- Starting position
  - Initial DWF states in the WWTP model according to seasonal circumstances
    - Season specific constants for:
      - Average temperatures on a monthly base
      - Population equivalents (influence of tourism during summer)
        - Summer (July & August)
          - 100 % of PE through tourism
        - Transition (May & July)
          - 50 % PE through tourism
      - Number of lanes in operation
        - Summer and transition
          - 2 lanes
        - Else
          - 1 lane

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Methodology

- Step 1
  - Objective
    - Search for the largest WWTP inflow the plant can handle (i.e. $Q_{WWTP,in,max} = Q_{SN,out,ref}$) and optimize the necessary aerated volume
  - Actions
    - Simulation of the expected rainfall event
      - With maximum discharges according to the hydraulic capacity of the trunk sewer and particular capacities of pumps and throttles for 1 day according to the rainfall prediction
    - Simulation of the WWTP with the resulting hydro- and pollutograph

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Methodology

- Step 2
  - Objective
    - Model predictive control of the sewer network according to the reference inflow estimated in step 1
  - Actions
    - Simulation of the first day of the expected rainfall event
      - Objectives
        - Stay below $Q_{SN,out,ref}$
        - Homogenous distribution of the total retention volume within the receiving water categories 1 to 3
        - Weighted outflow according to the receiving water categories

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Methodology

- Next step
  - Objective
    - Model predictive control of the sewer network for the following periods of the event according to the reference inflow estimated in step 1
  - Actions
    - Go back to step 2
- Repeat from step 1 for subsequent events

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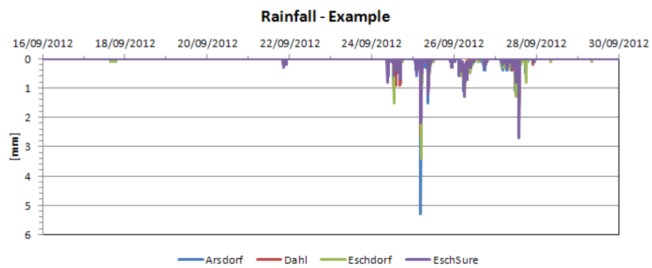
Example

- Rainfall event September 2012



- Heavy storm event with
  - Quite long proceeding dry weather flow period
  - Consecutive sub events
  - Inhomogenious distribution

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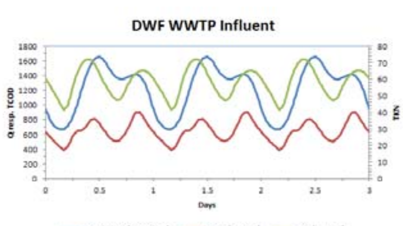
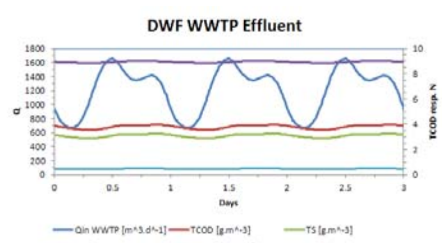
Example

- Dry weather operation according to German guidelines
  - Sludge age: 25d
  - DO = 1.5 mg/l





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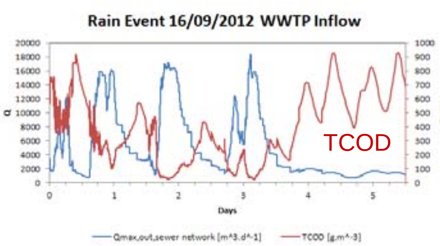
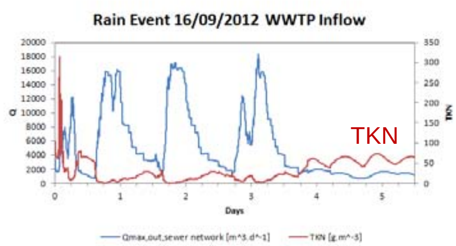
Example

- Modelling of the maximum sewer network outflow according to hydraulic capacities of the trunk sewer network





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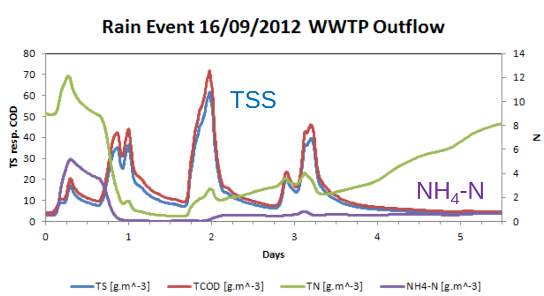
Example

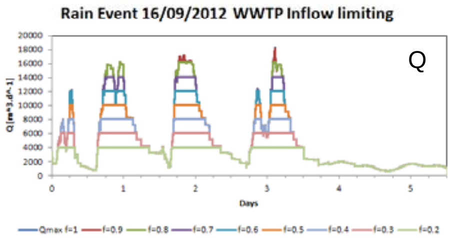
- Modelling of this hydrograph at the WWTP

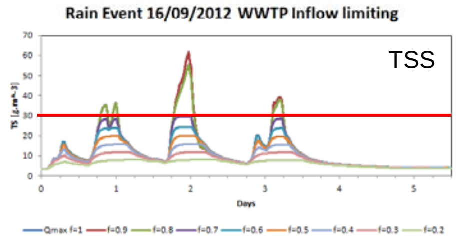


Par.	Limit	Condition
TSS	< 30 mg/l < 30 mg/l	24 h mixed sample 2 h mixed sample
TCOD	< 75 mg/l O_2 < 90 mg/l O_2	24 h mixed sample 2 h mixed sample
NH_4-N	< 3 mg/l < 3 mg/l	24 h mixed sample 2 h mixed sample
TN	< 15 mg/l < 15 mg/l	24 h mixed sample 2 h mixed sample

Case study ReseauSure
Example

- Estimation of a treatable hydrograph according to ASM3m





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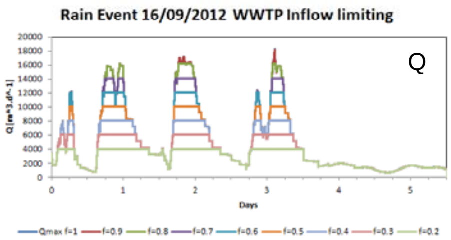
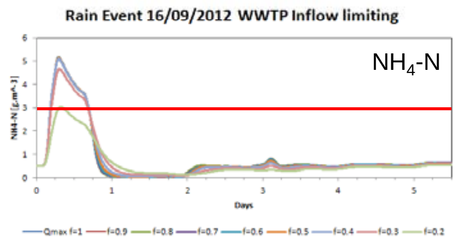
Example

- Estimation of a treatable hydrograph according to ASM3m





  - Both the prediction horizon $H_{P,WWTP}$ and the control horizon $H_{C,WWTP}$ seem to be appropriate for the WWTP

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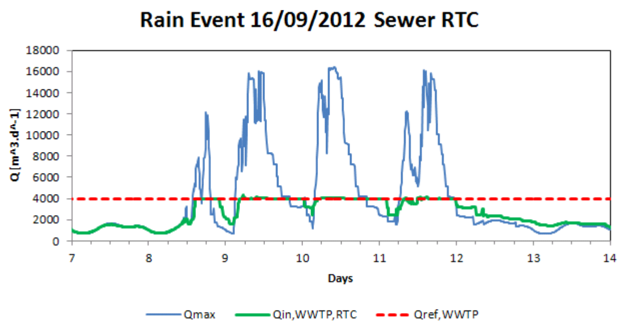
Example

- MPC of the sewer system pumps/throtles delivers the $Q_{WWTP,in,max}$



Summary

- MPC for the online estimation of allowable reference hydro- and pollutographs ($Q_{WWTP,in,ref}$) allows for an optimized integrated operation according to legal effluent limits at the WWTP
- The methodology strongly depends on the next day rainfall forecast
- The integrated operation can be directly linked to the limiting factors allowing for a detailed investigation of appropriate prediction and control horizons
- Kalman filtering for WWTP is still a challenge
- The example shows how to avoid problematic NH_4-N effluent concentrations
- The example also shows that systems with seasonally different operation profit from an integrated approach

Acknowledgements

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Fonds National de la Recherche Luxembourg: www.fnr.lu

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