Technical University of Denmark DTU

Modeling and control of urban drainage-wastewater systems

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The challenges of urban drainage-wastewater systems

Since 2007- … a range of activities

Universities + research institutions + water utilities + consultants

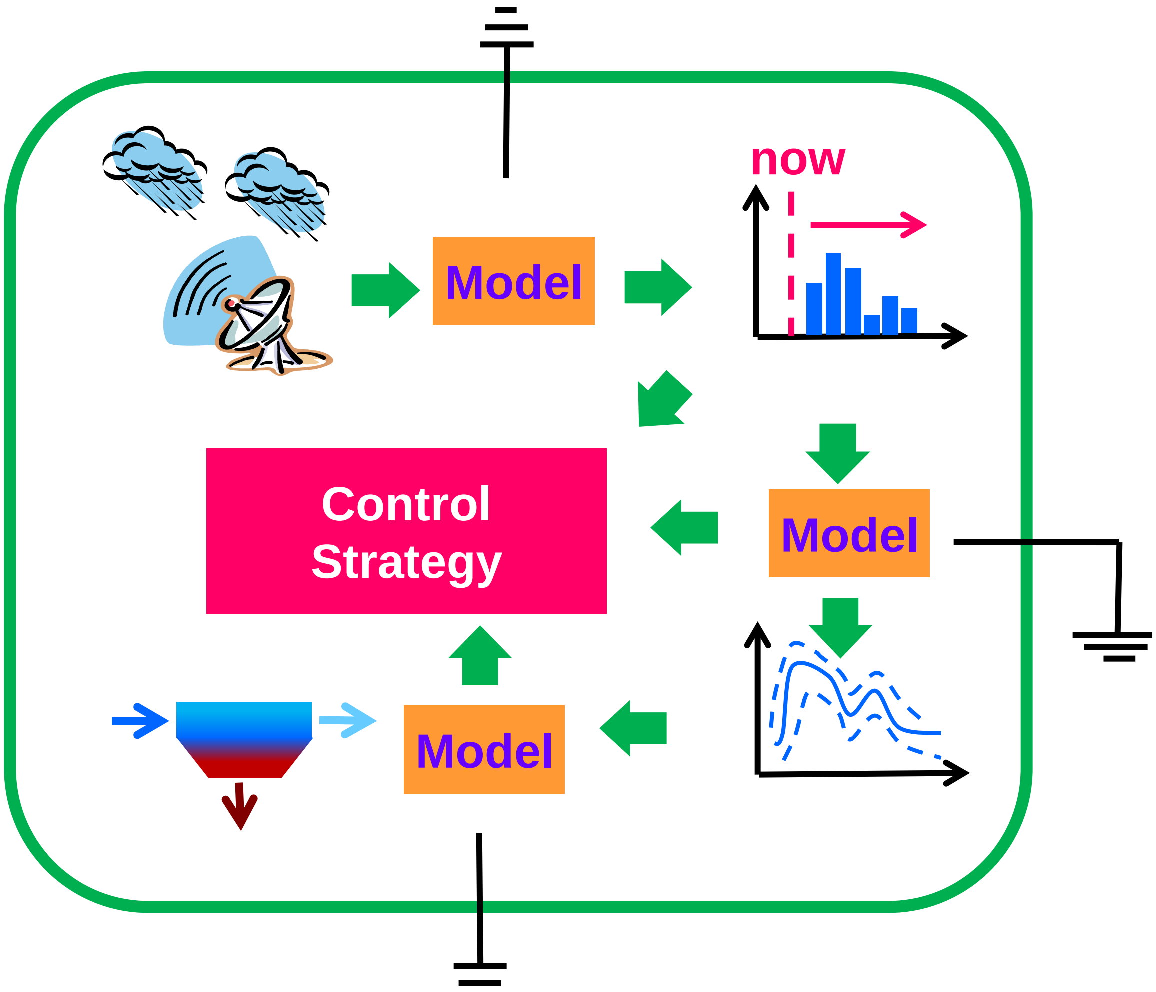
- Many projects
  - Storm- and Wastewater Informatics (SWI)
  - Klimaspring
  - Prepared
  - AMOK
  - Water Smart Cities (www.watersmartcities.ennv.org)
- Industrial PhDs
- Industrial postdocs
- Many MSc theses

The SWI philosophy

Storm- and Wastewater Informatics

Measurements + Models + Forecasts + Uncertainty =

The happy operator



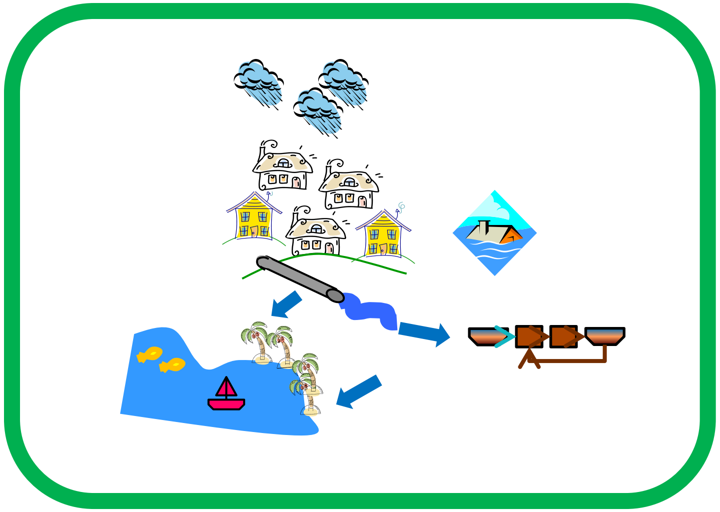
- Rainfall measurements
- Short-term rainfall forecasts
- Continuously updated hydrodynamic models
- Stochastic rainfall-runoff forecast
- WWTP forecast models
- MPC strategy addressing uncertainty

Uncertainty

Acknoledging that we cannot know everything

Measurements + Models + Forecasts + **Uncertainty** =

The happy operator



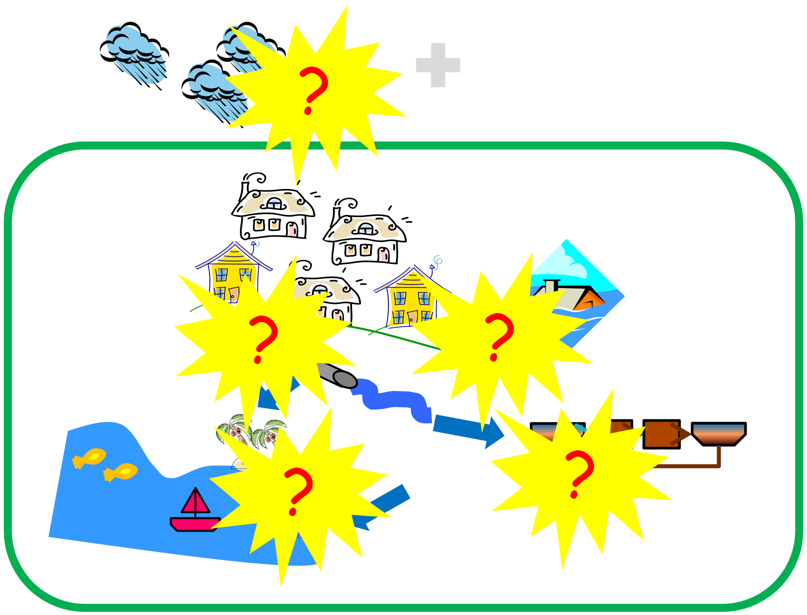
y=m(t,x,u,θ)

Uncertainty

Acknoledging that we cannot know everything

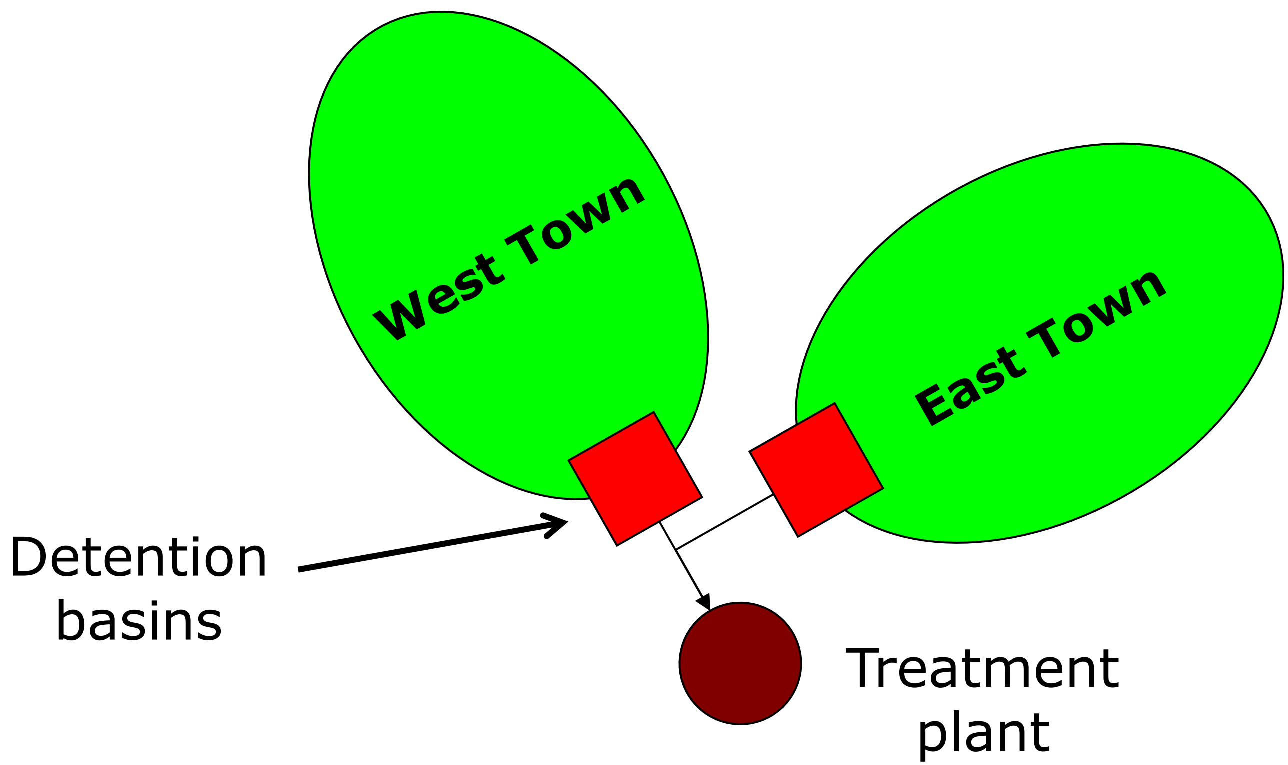
Measurements   Models + Forecasts + **Uncertainty** =

The happy operator

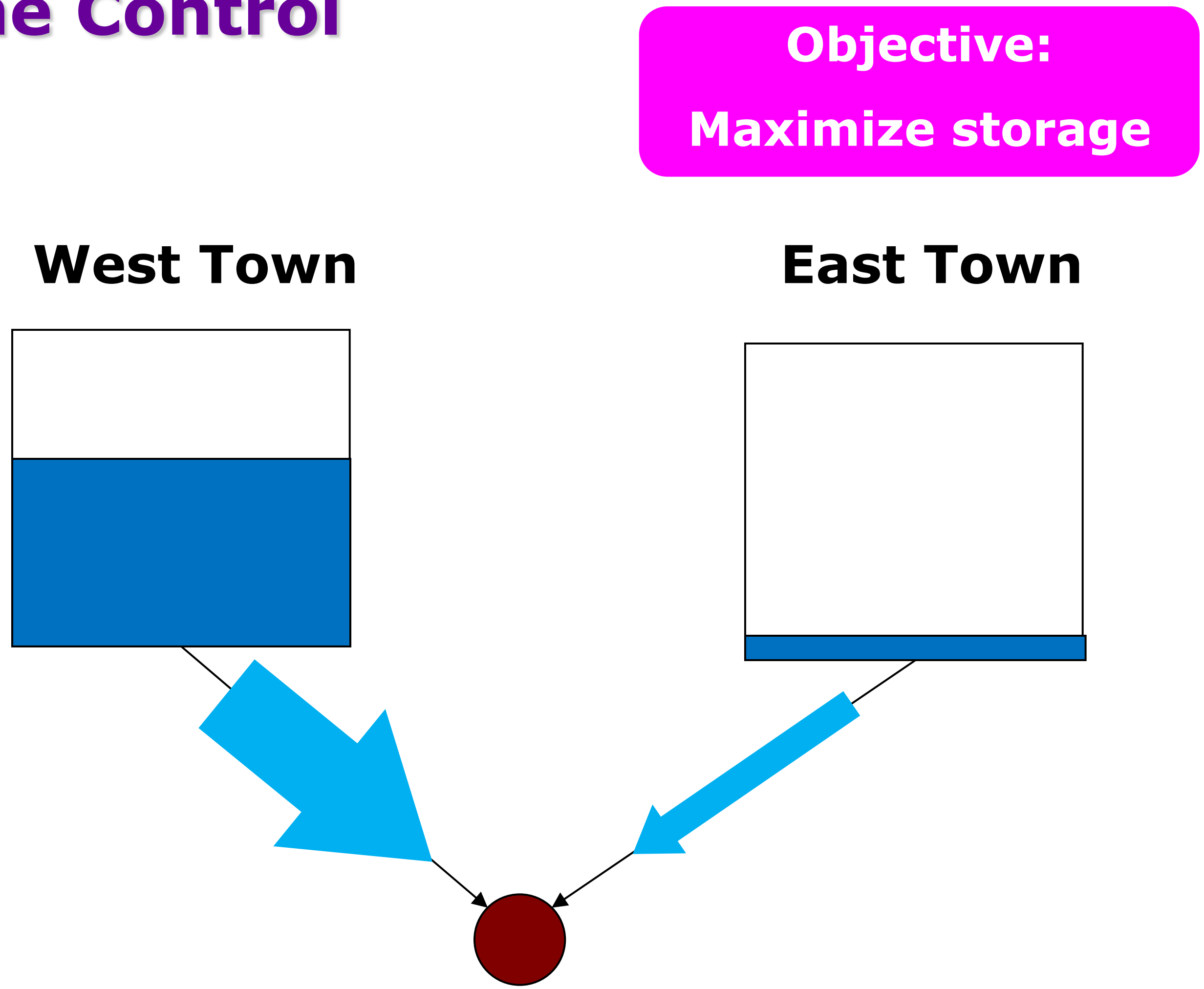


$$O(x,t)+\varepsilon(x,t)=m(t,x,u,\varepsilon_u,\theta,\varepsilon_\theta)+\varepsilon_u(x,t,u,\varepsilon_u,\theta,\varepsilon_\theta)$$

Why uncertainty matters
Didactical example



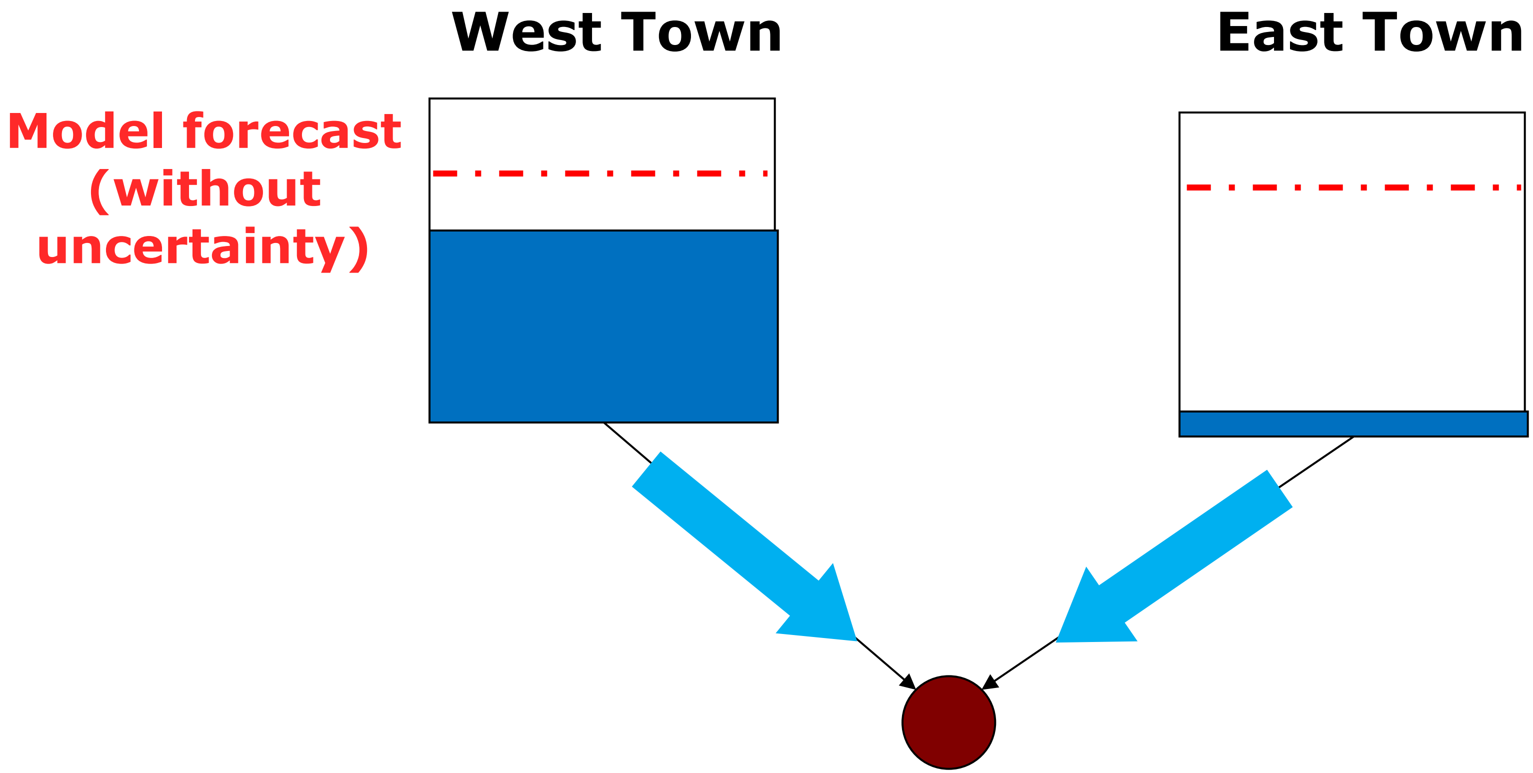
Real Time Control



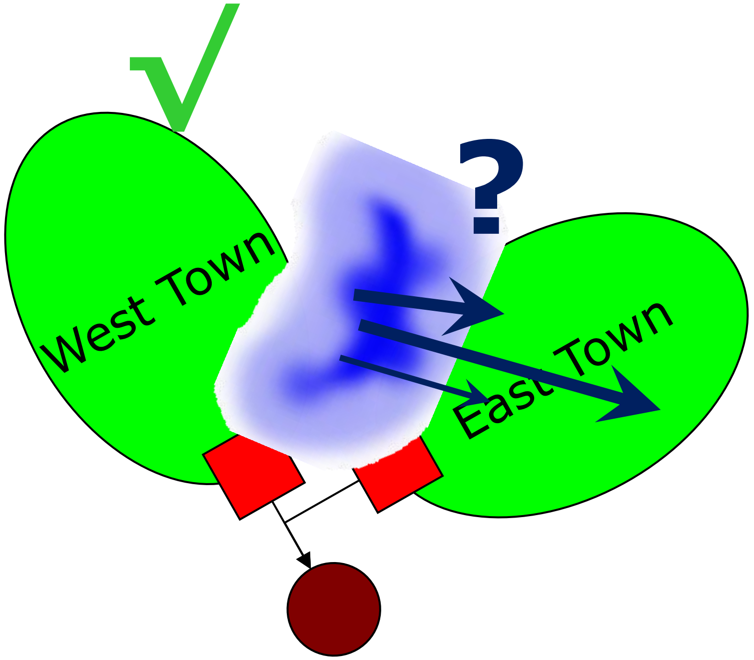
“Traditional” MPC

Objective:

Maximize future storage

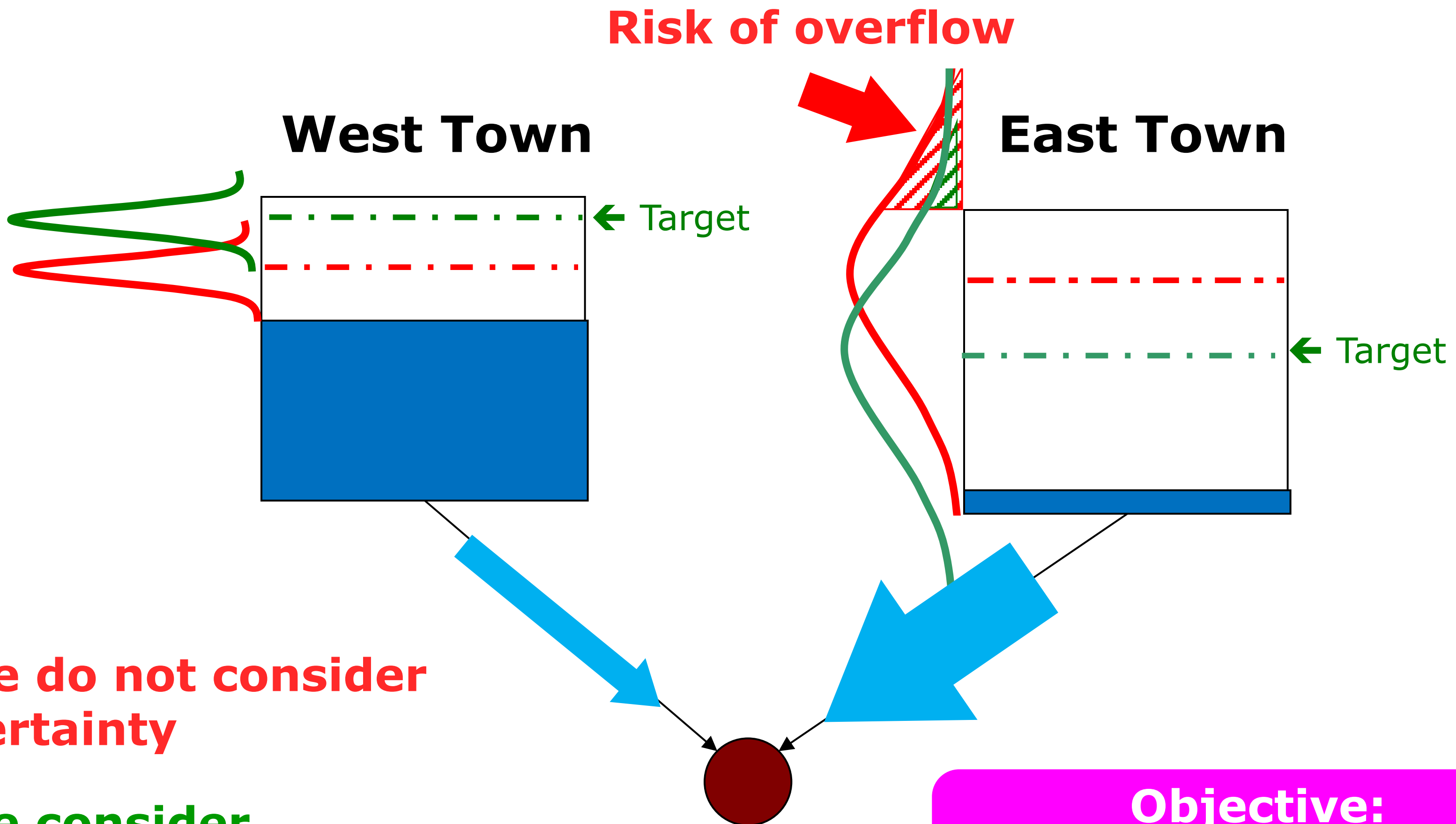


Risk-based Model Predictive Control



Rainfall evolution is uncertain

Risk-based Model Predictive Control



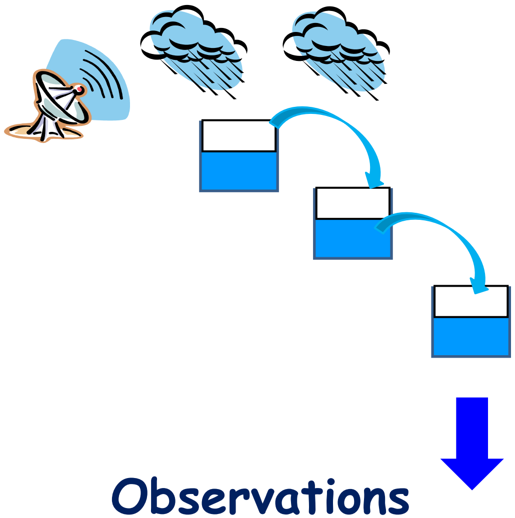
If we do not consider uncertainty

If we consider uncertainty

Objective:

Minimize CSO risk

Stochastic runoff forecasts



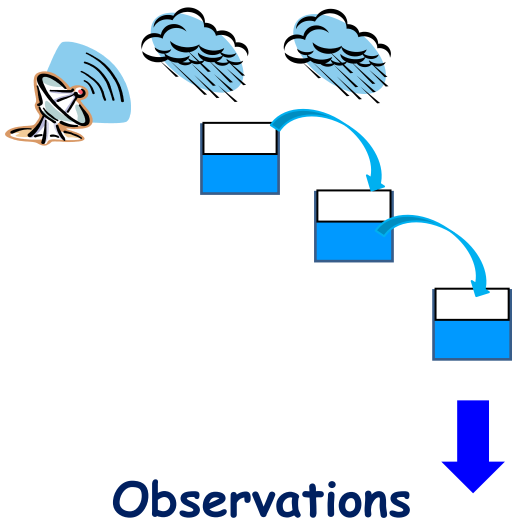
$$dS_1 = \left(A \cdot P + a_0 - \frac{1}{k} S_1\right) dt$$

$$dS_2 = \left(\frac{1}{k} S_1 - \frac{1}{k} S_2\right) dt$$

$$dS_3 = \left(\frac{1}{k} S_2 - \frac{1}{k} S_3\right) dt$$

Löwe et al. (2014). J. Hydrology, 512, doi:10.1016/j.jhydrol.2014.03.027 .

Stochastic runoff forecasts



$$dS_1 = \left(A \cdot P + a_0 - \frac{1}{k} S_1\right) dt + noise$$

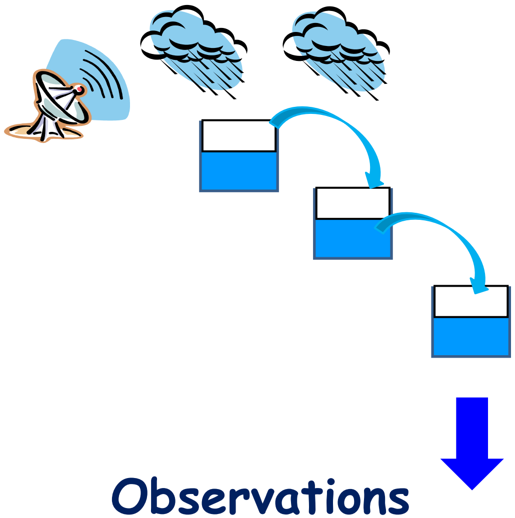
$$dS_2 = \left(\frac{1}{k} S_1 - \frac{1}{k} S_2\right) dt + noise$$

$$dS_3 = \left(\frac{1}{k} S_2 - \frac{1}{k} S_3\right) dt + noise$$

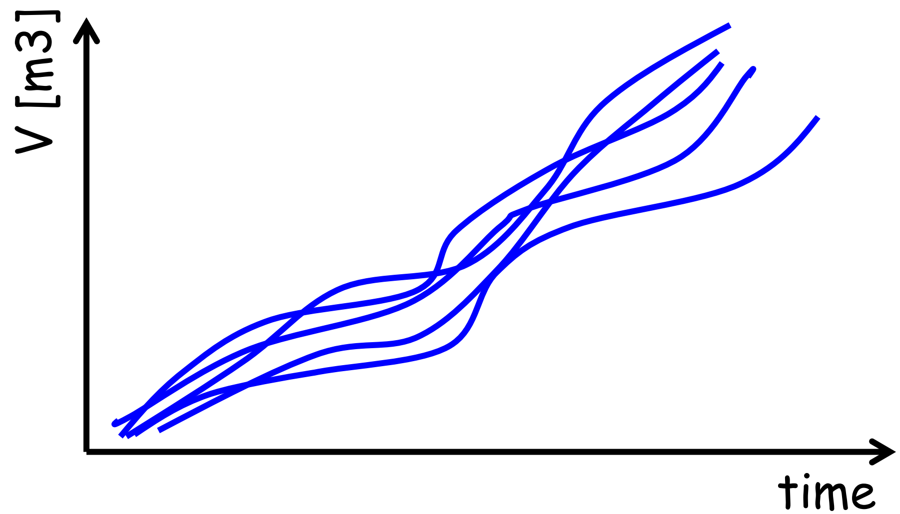
$$Q_t = \left(\frac{1}{k} S_3 + D\right) + \varepsilon_t$$

Löwe et al. (2014). J. Hydrology, 512, doi:10.1016/j.jhydrol.2014.03.027 .

Stochastic runoff forecasts



1000 simulations



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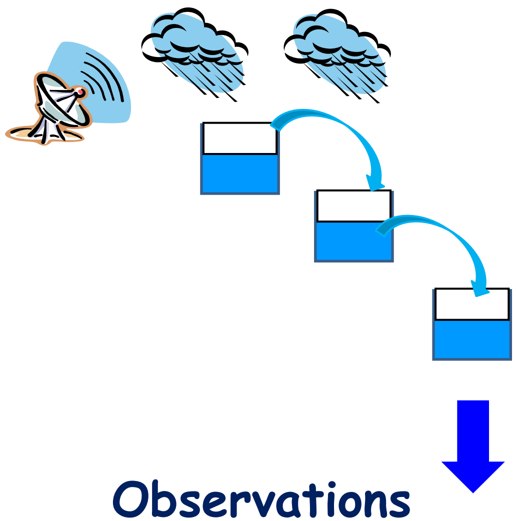
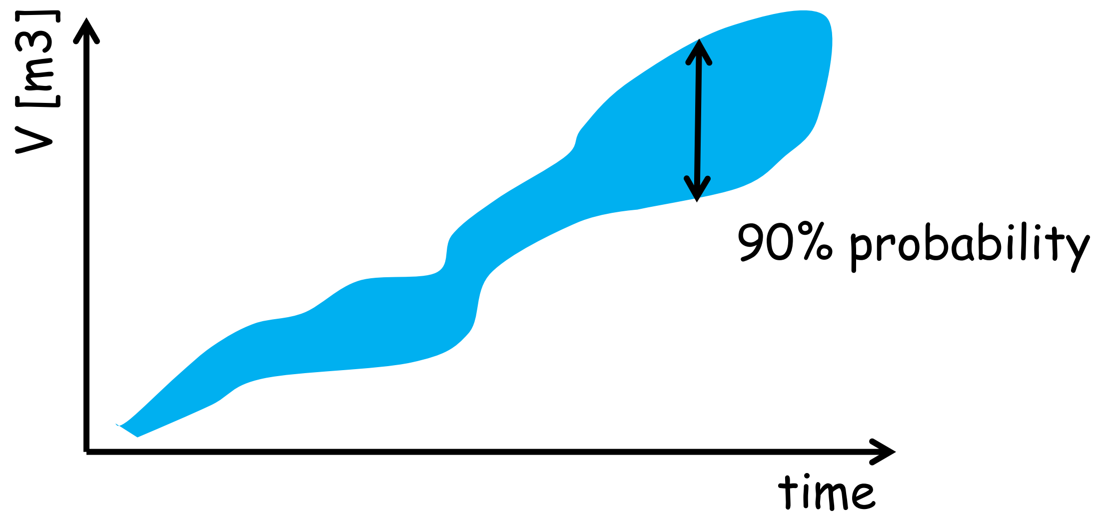
Stochastic runoff forecasts



1000 simulations



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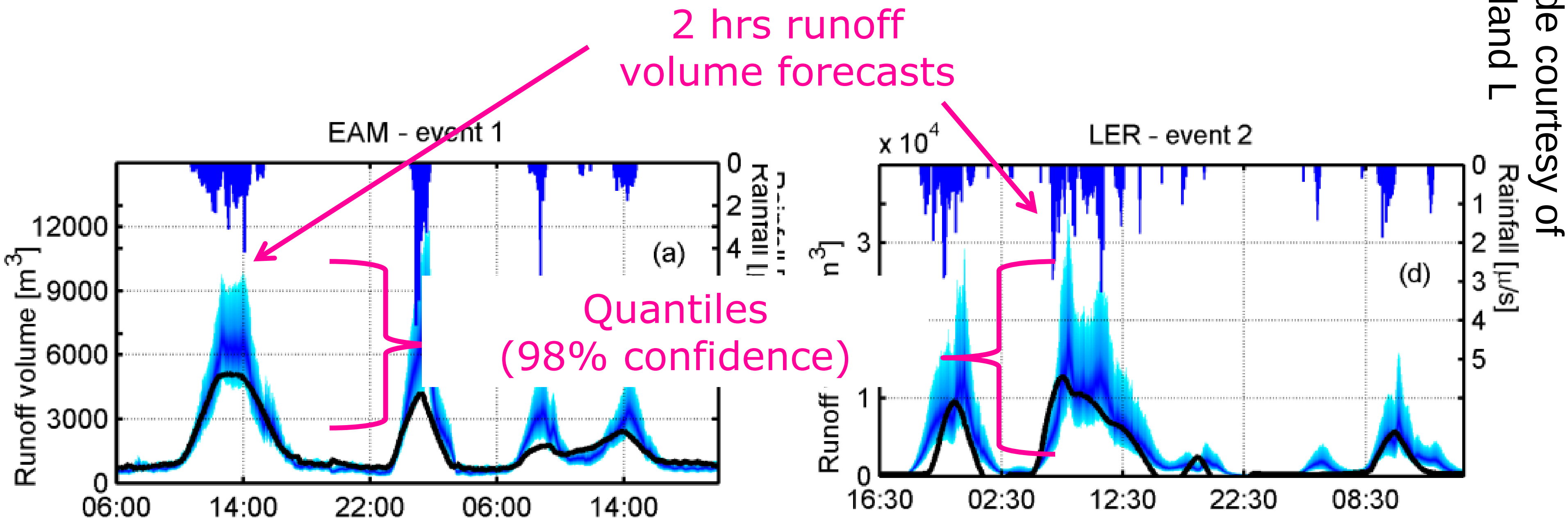
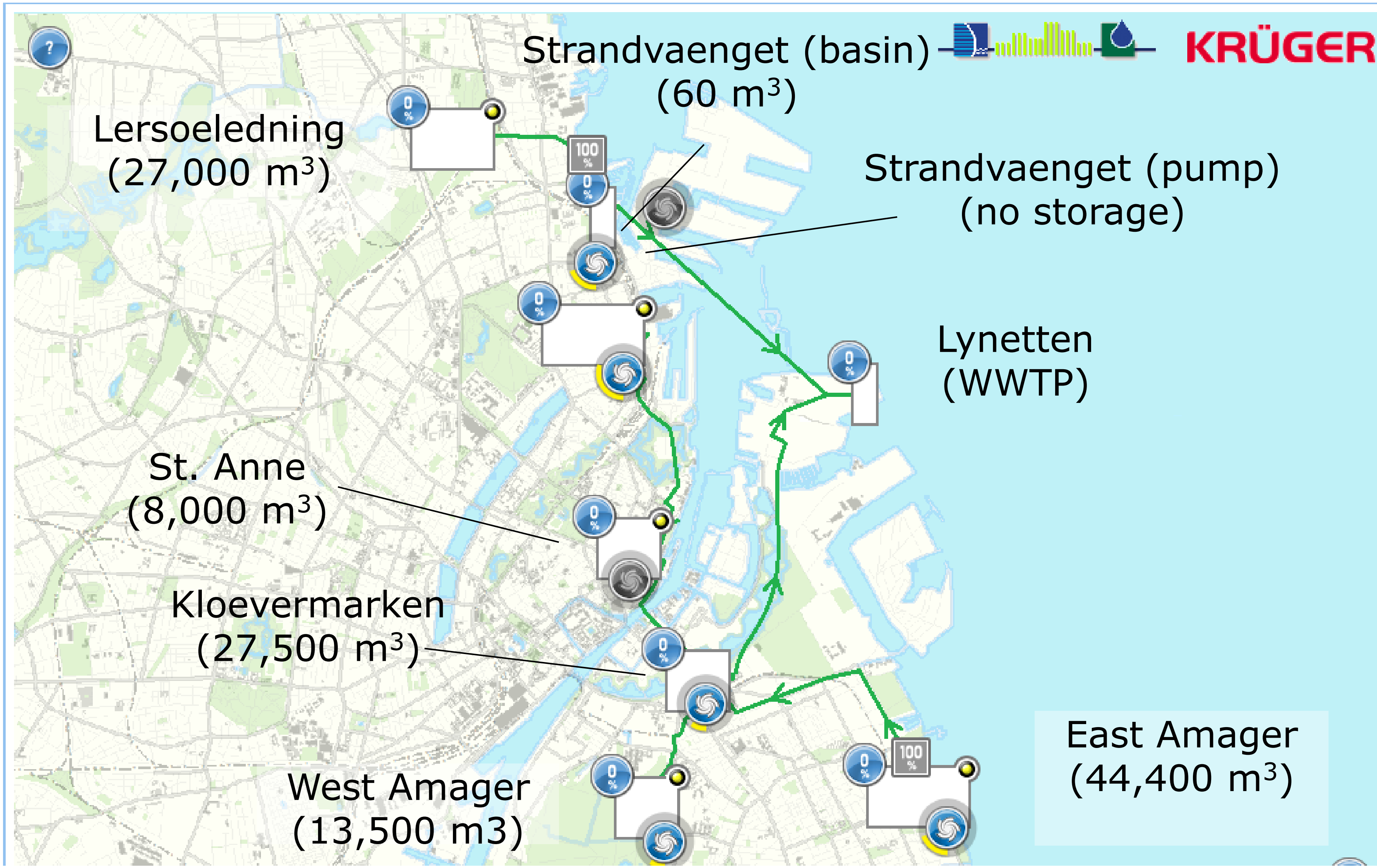
Stochastic runoff forecasts

Slide courtesy of Roland L



The Lynetten catchment
Central Copenhagen, Denmark

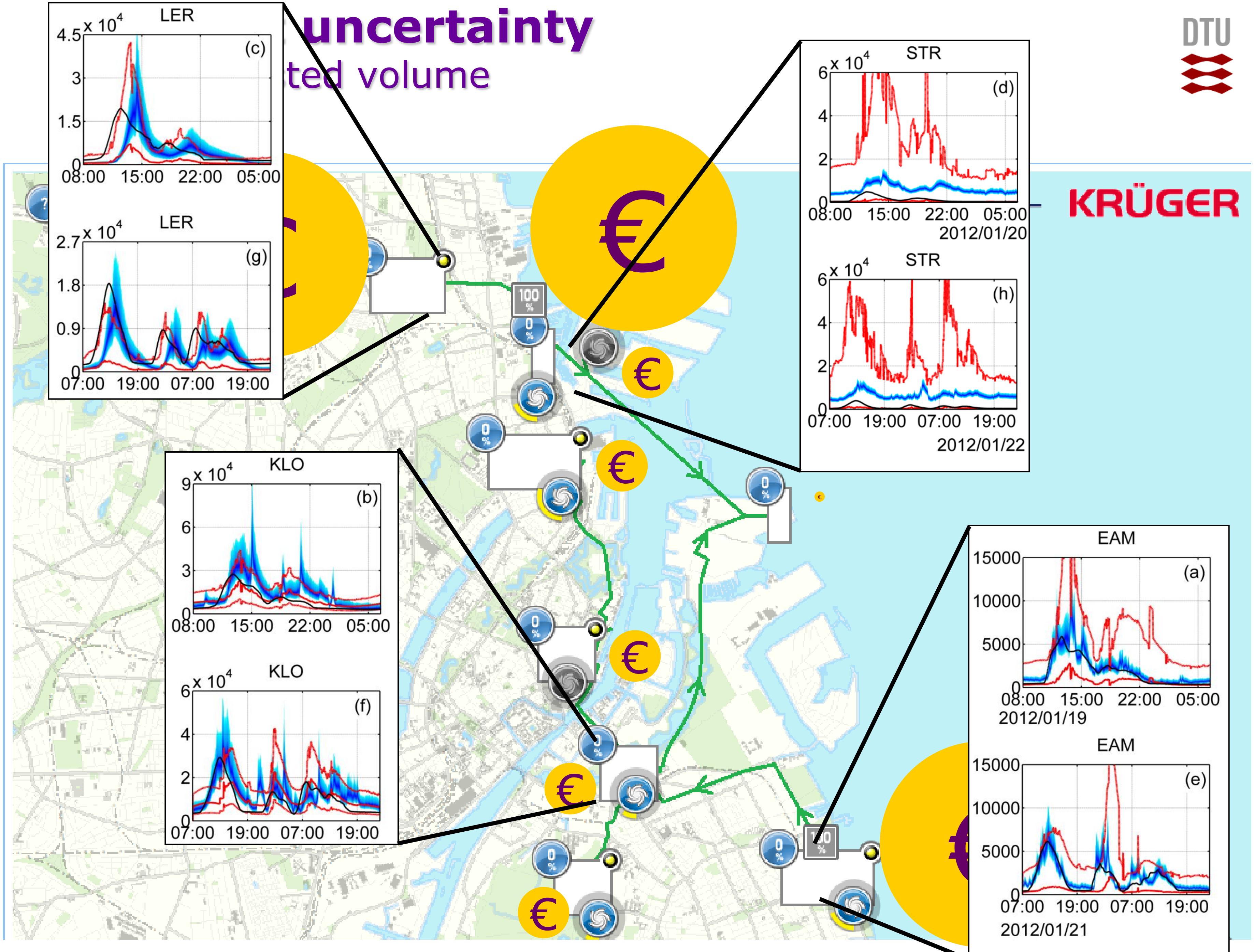


Sensitivity of overflow recipient

CSO "price"

uncertainty

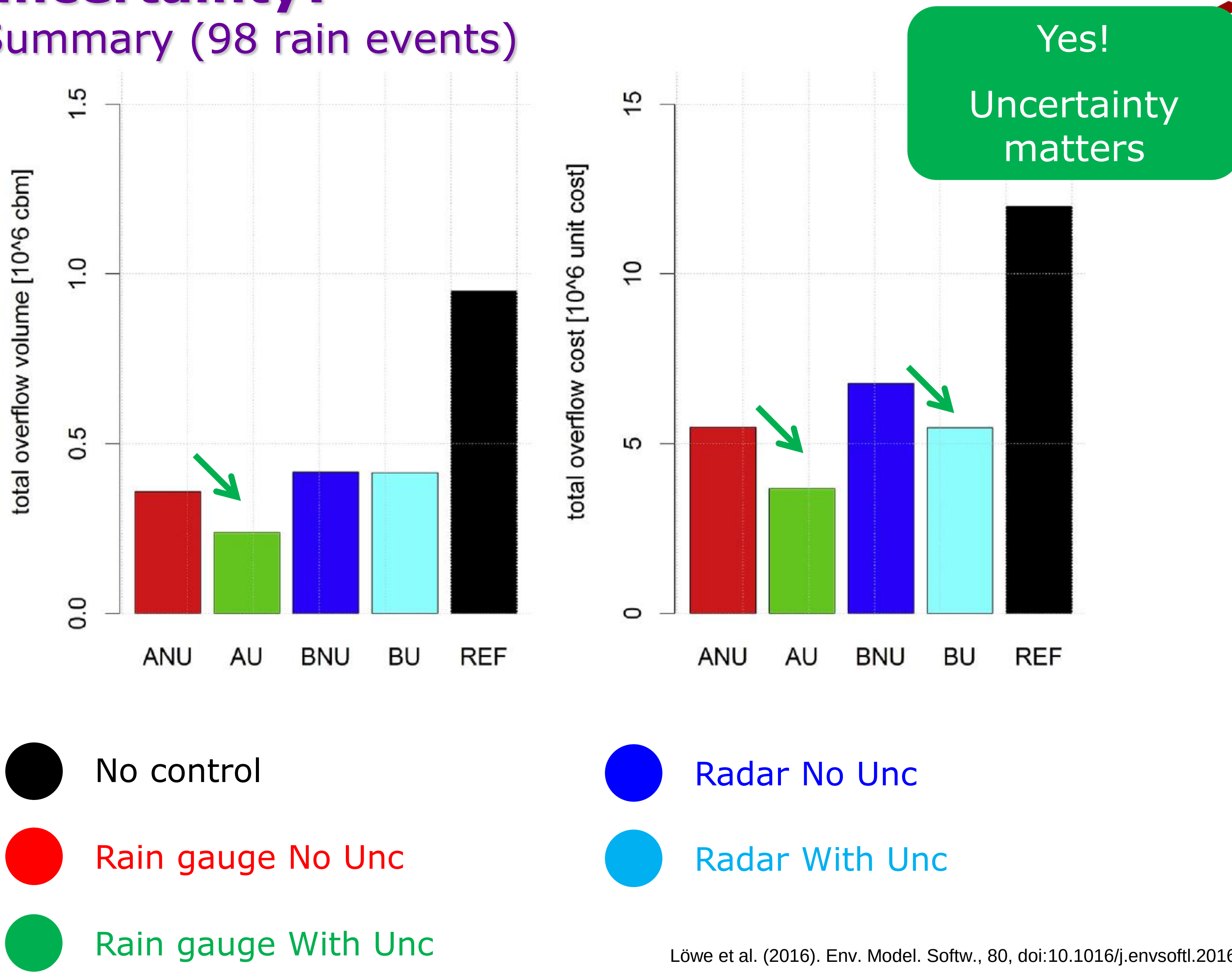
ted volume



KRÜGER

Does it pays off to include forecast uncertainty?

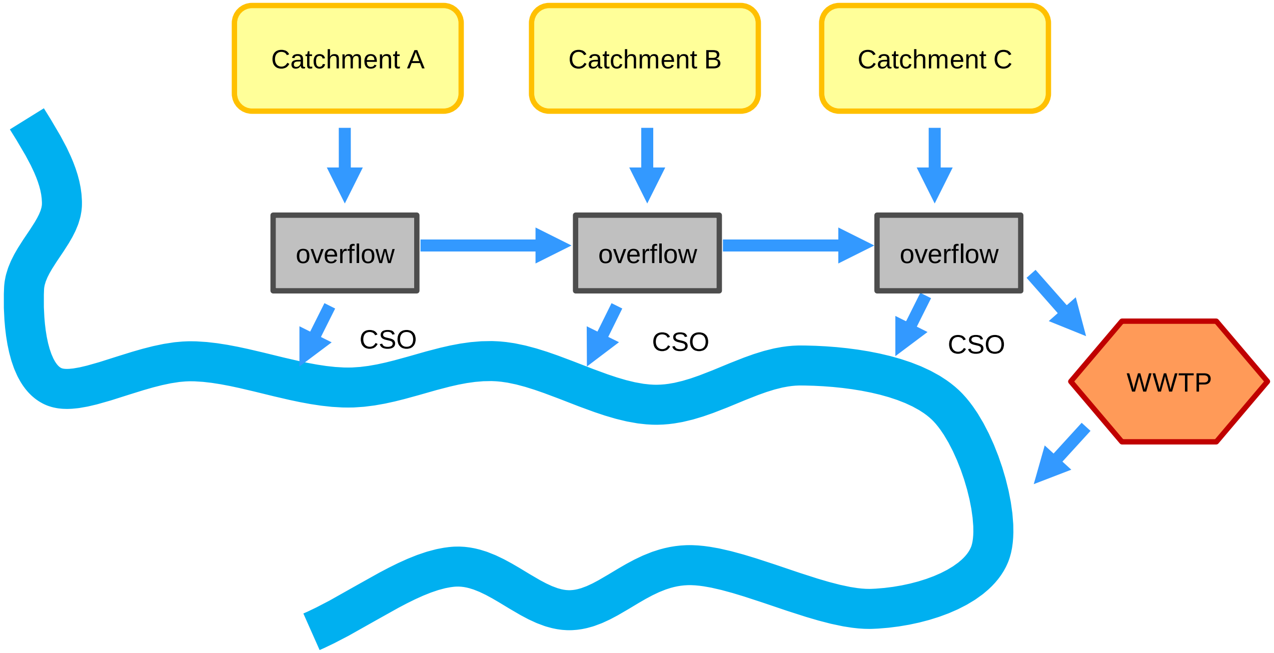
Summary (98 rain events)



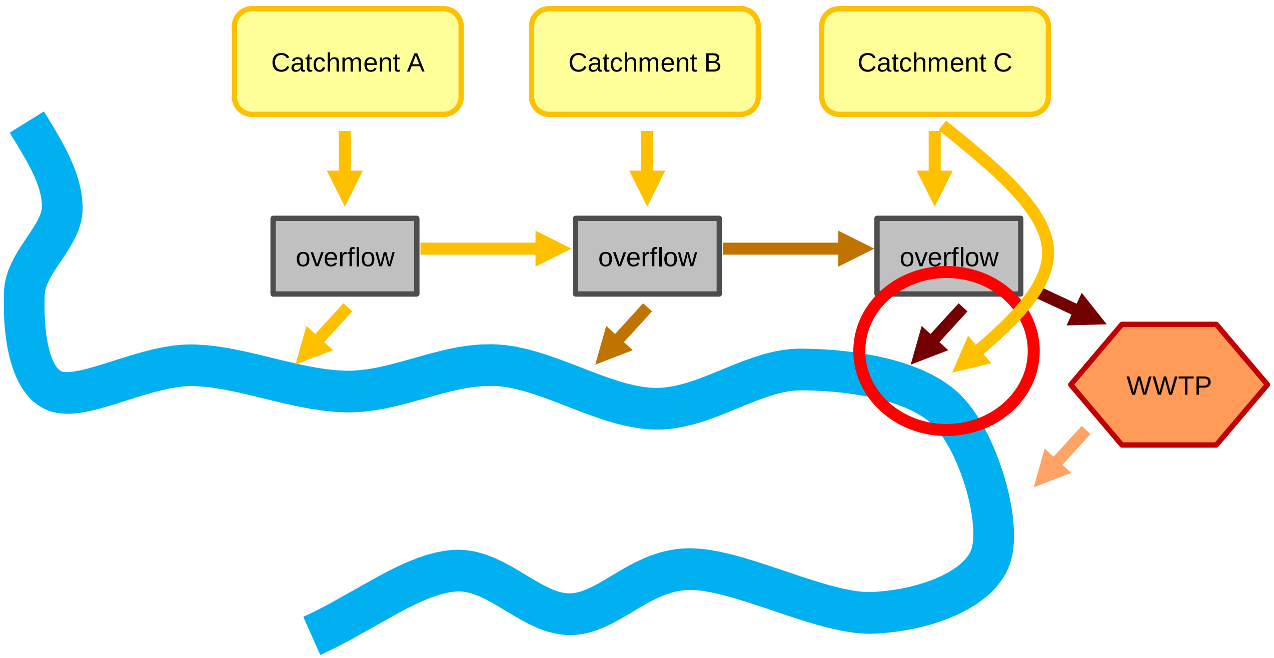
Löwe et al. (2016). Env. Model. Softw., 80, doi:10.1016/j.envsoftl.2016.02.027

Water-quality control strategy

- The majority of existing control considers only water volumes

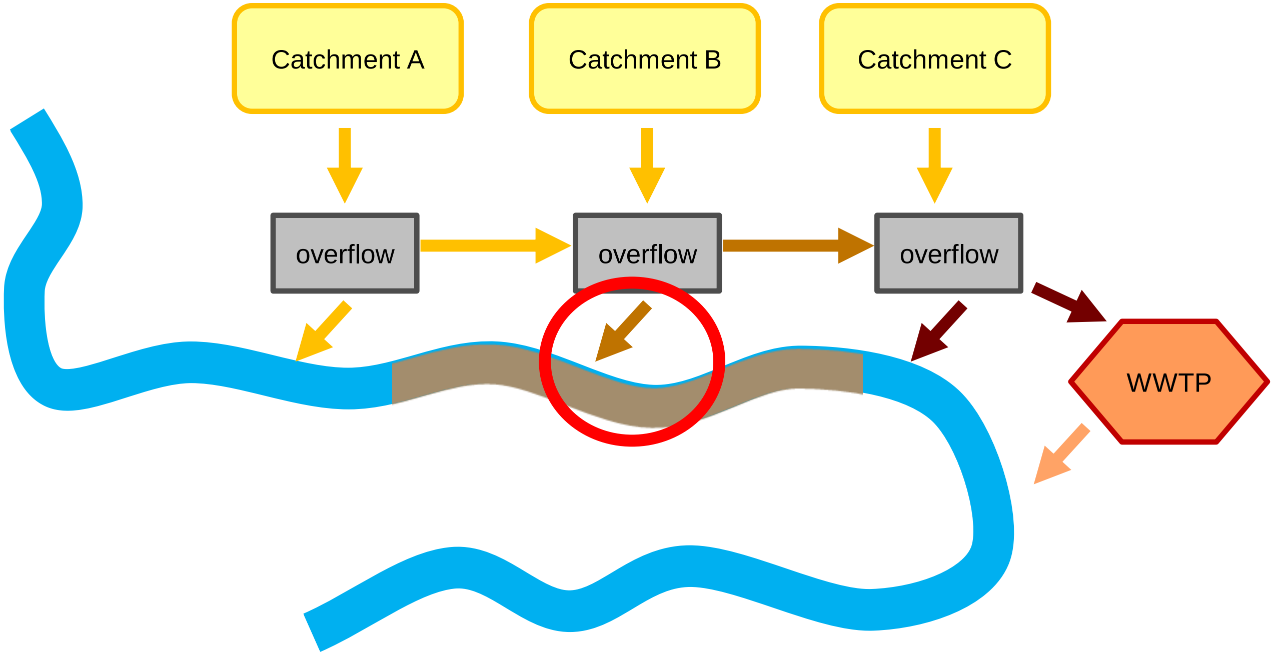


Water-quality control strategy



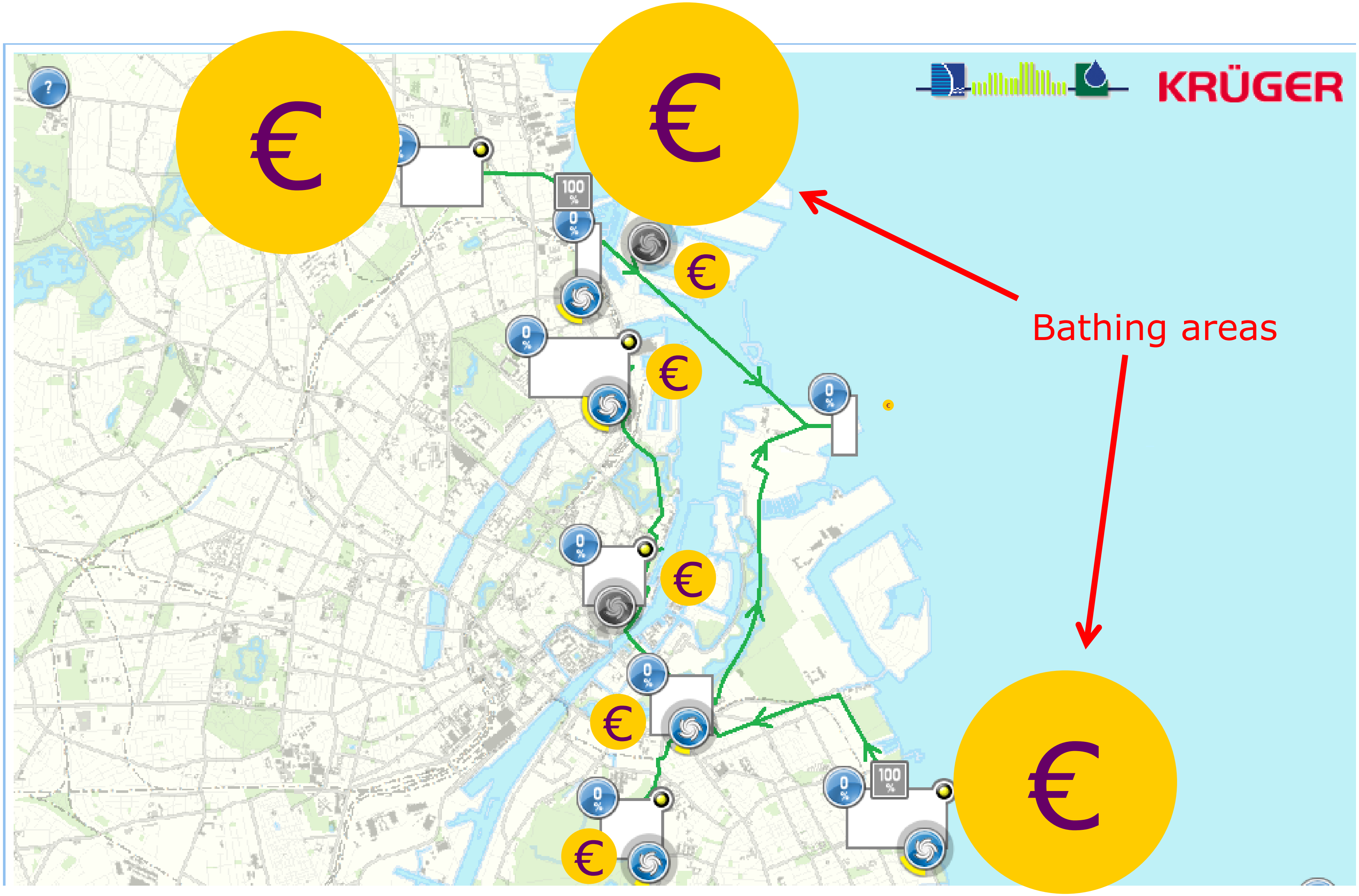
- Prioritize the points of the system with the higher concentrations
- Allow discharge of less polluted water

Water-quality control strategy

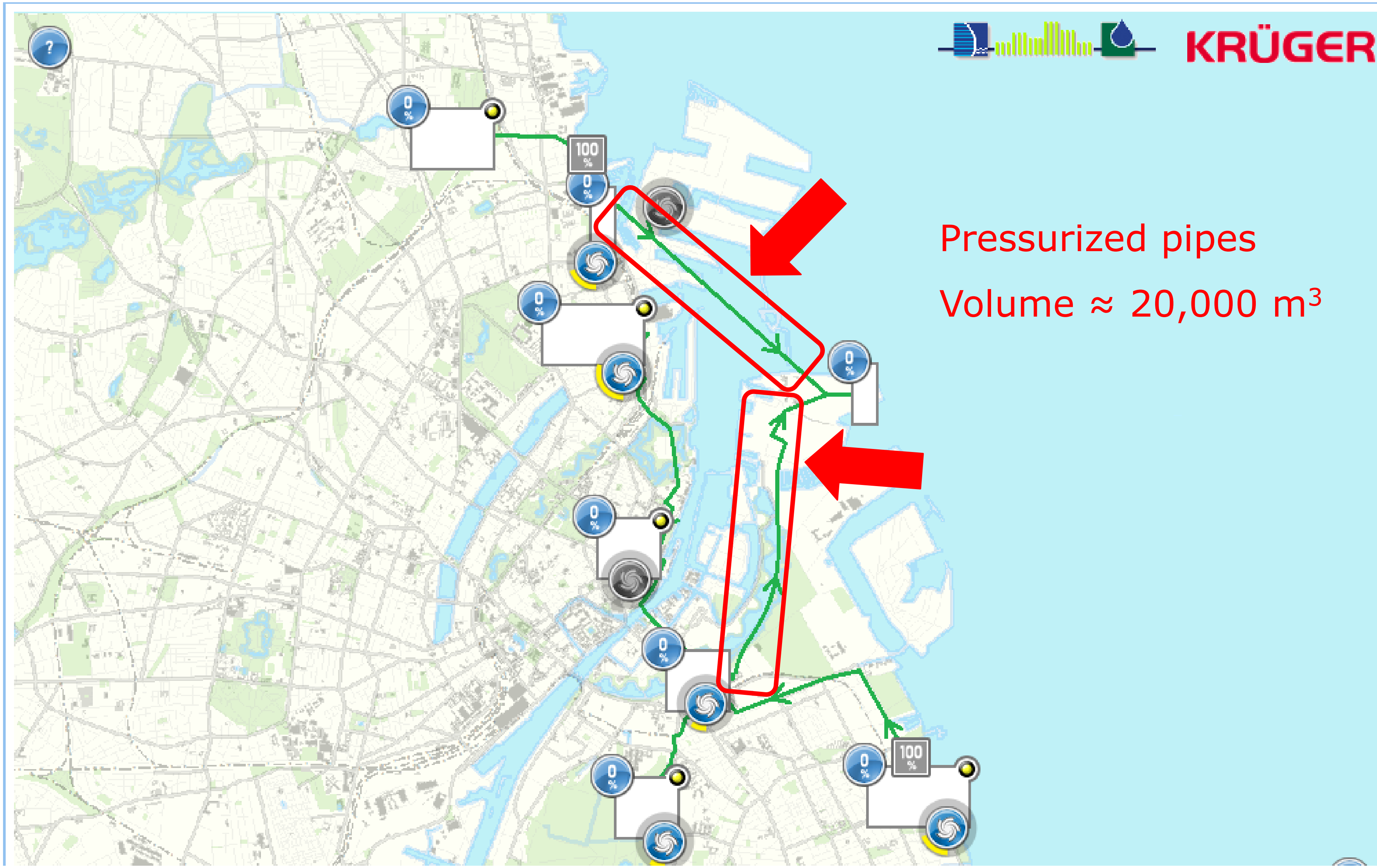


- Allow overflow where the recipient quality status will not be strongly affected

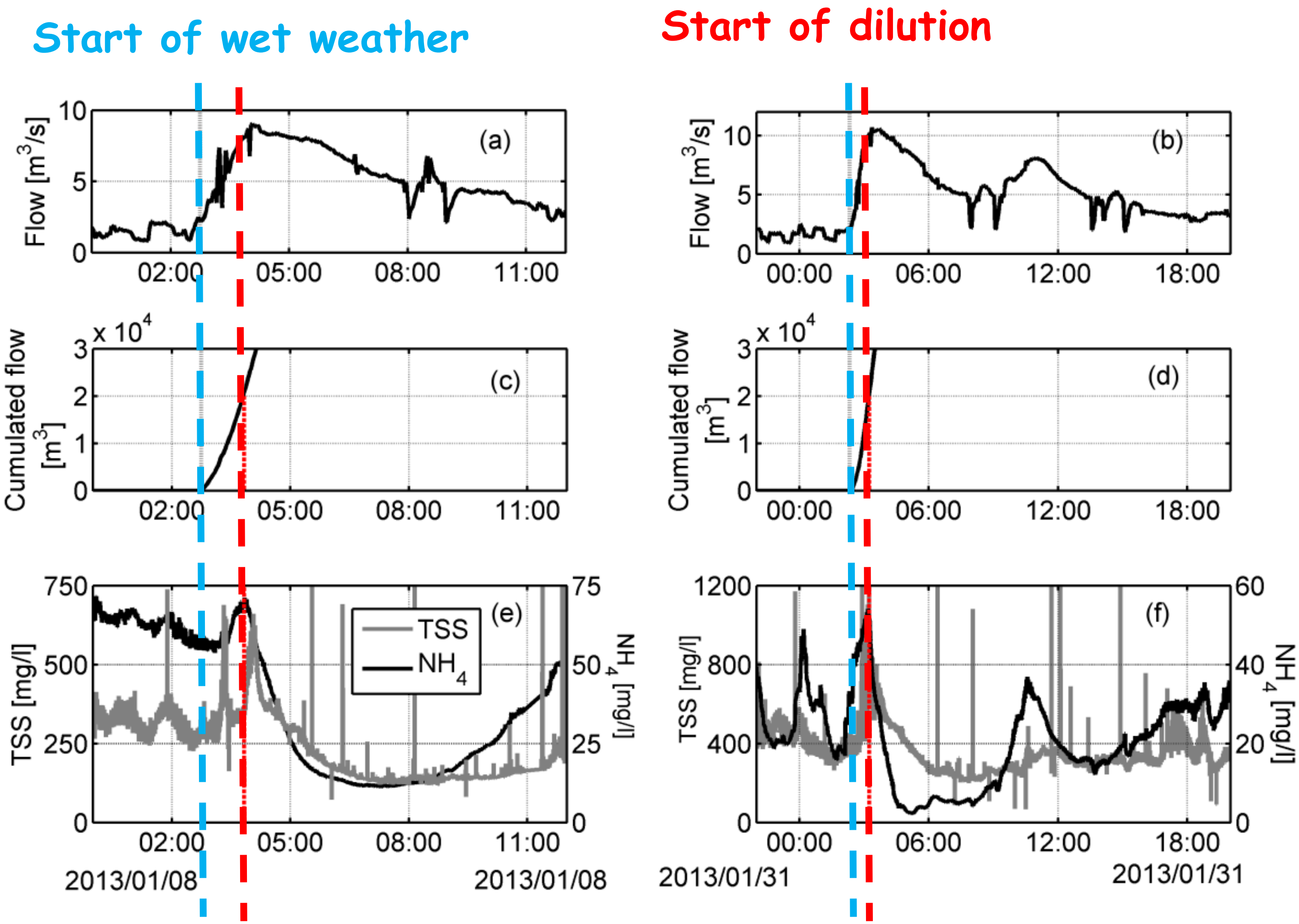
Sensitivity of overflow recipient
CSO "price"



Inlet to Lynetten WWTP



Concentration behaviour at Lynetten inlet
(data from DanEAU project)



From Vezzaro L., Christensen, M.L., Thirsing, C., Grum, M., Mikkelsen, P.S. (2014) Water quality-based real time control of integrated urban drainage: a preliminary study from Copenhagen, Denmark, Procedia Engineering 70, 1707-1716

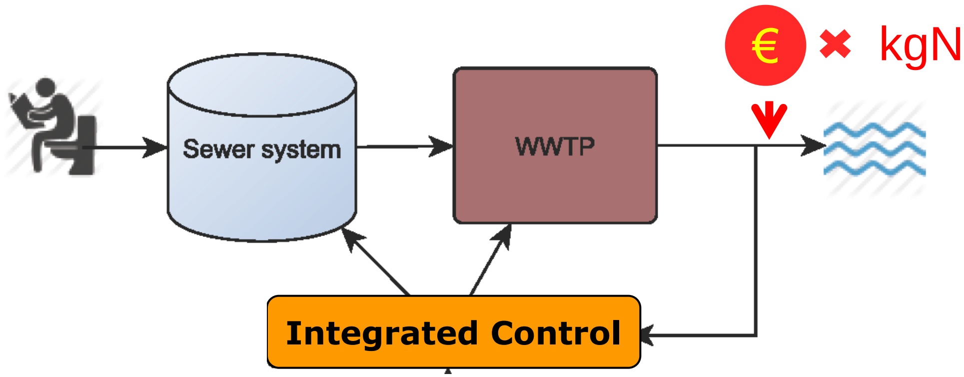
Water quality based control is possible

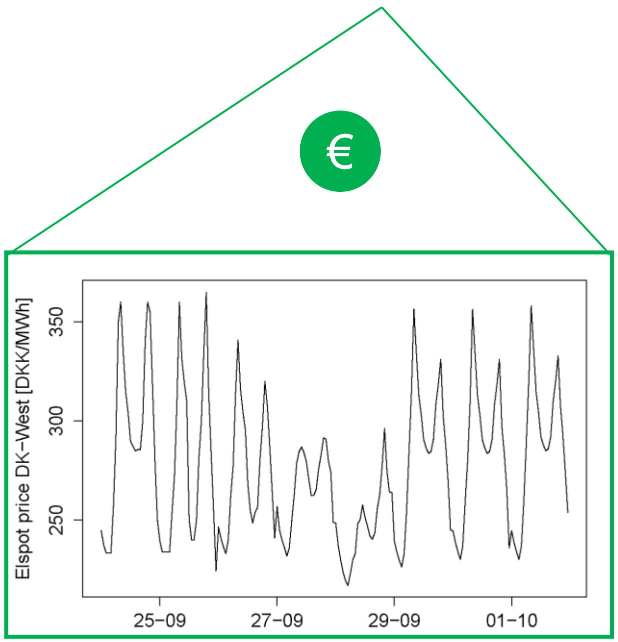
Once beach is contaminated, is as important as the other CSO

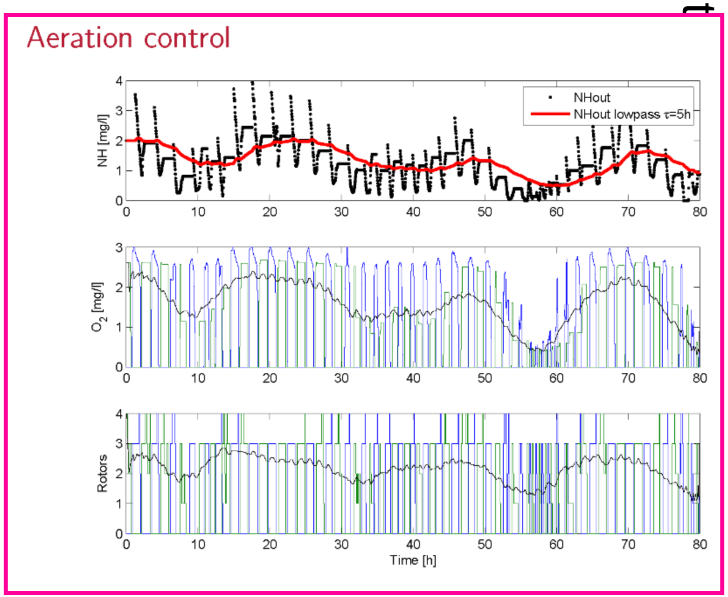
As long as the WWTP inlet is dirtier, let's try to protect it

Vezzaro et al. (2014), Procedia Engineering **70**, doi:10.1016/j.proeng.2014.02.188

Controlling the WWTP based on energy prices



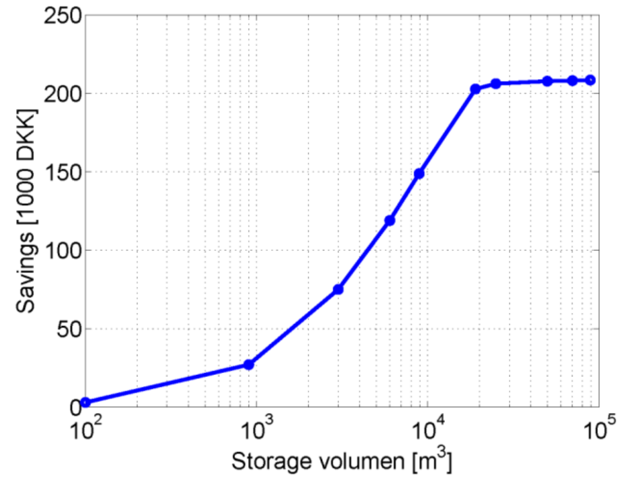


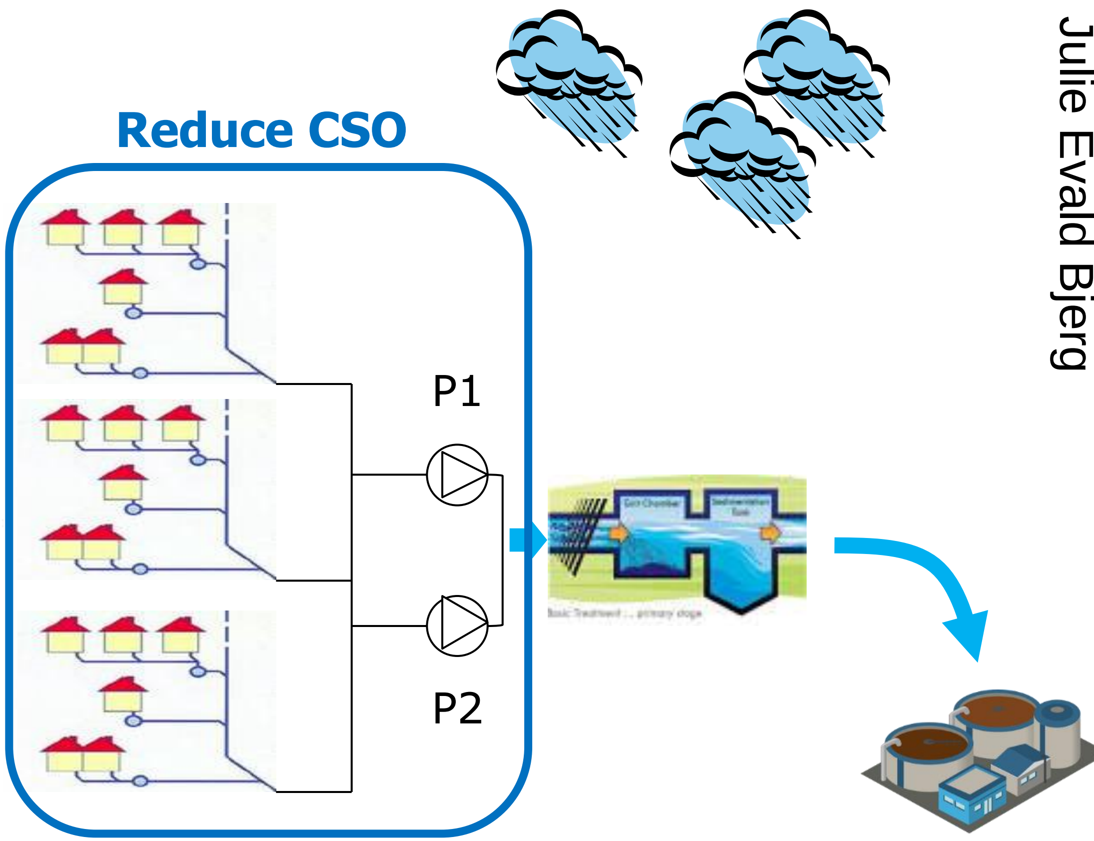


Slide courtesy of Rasmus Fogt Halvgaard

Controlling the WWTP based on energy prices – moving upstream

Sewer system annual Elspot savings

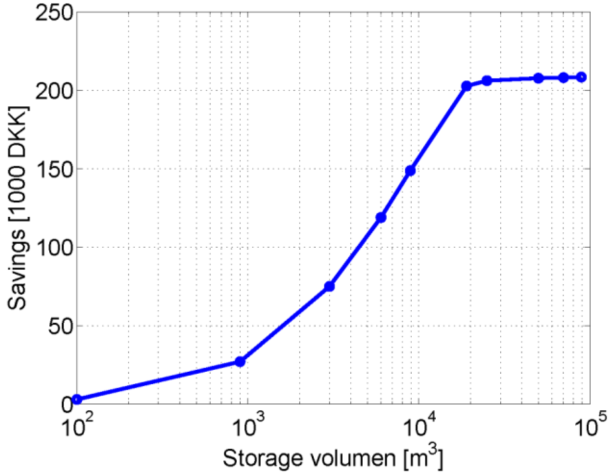




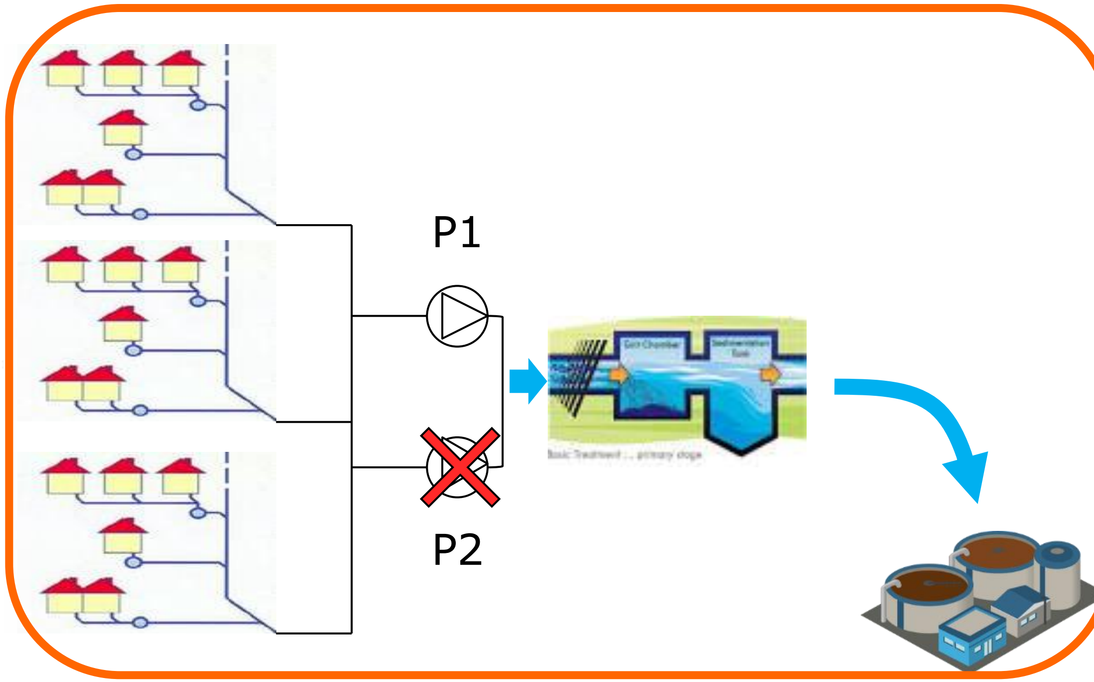
Slide courtesy of Rasmus Fogtmann Halvgaard and Julie Evald Bjerg

Controlling the WWTP based on energy prices – moving upstream

Sewer system annual Elspot savings

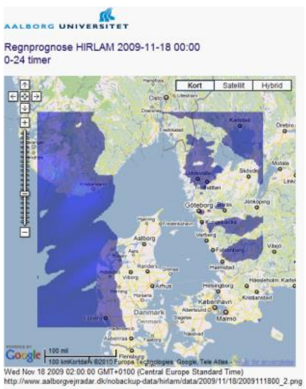


Optimize WWTP Operations

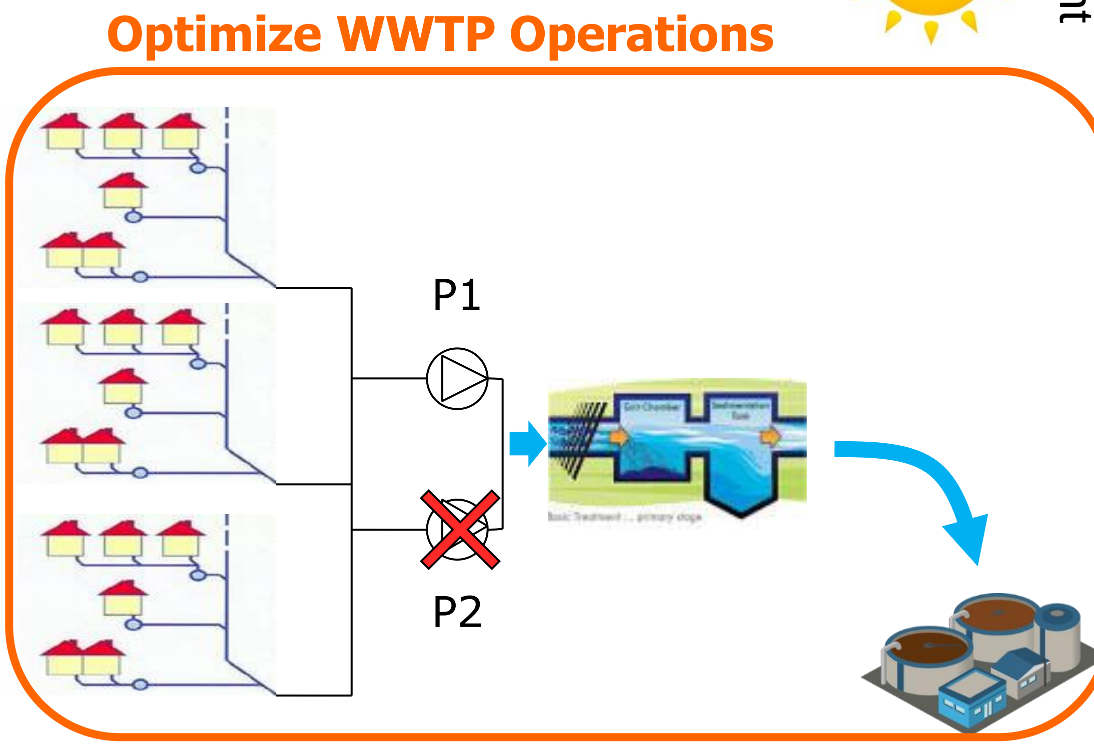


Slide courtesy of Julie Evald Bjerg and Vianney Courdant

Controlling the WWTP based on energy prices – moving upstream



Numerical Weather Prediction models are used to switch between the two controls



Slide courtesy of Julie Evald Bjerg and Vianney Courdant

Conclusions
towards a better control of drainage networks

- We have now new tools for on-line model-based operation of integrated urban wastewater systems (almost 10 years of research/development)

Measurements + **Models** + **Forecasts** + **Uncertainty** =

The happy operator

- And more will come in the next years…