Technical University of Denmark

# Ensemble based updating of distributed, physically based, urban drainage models

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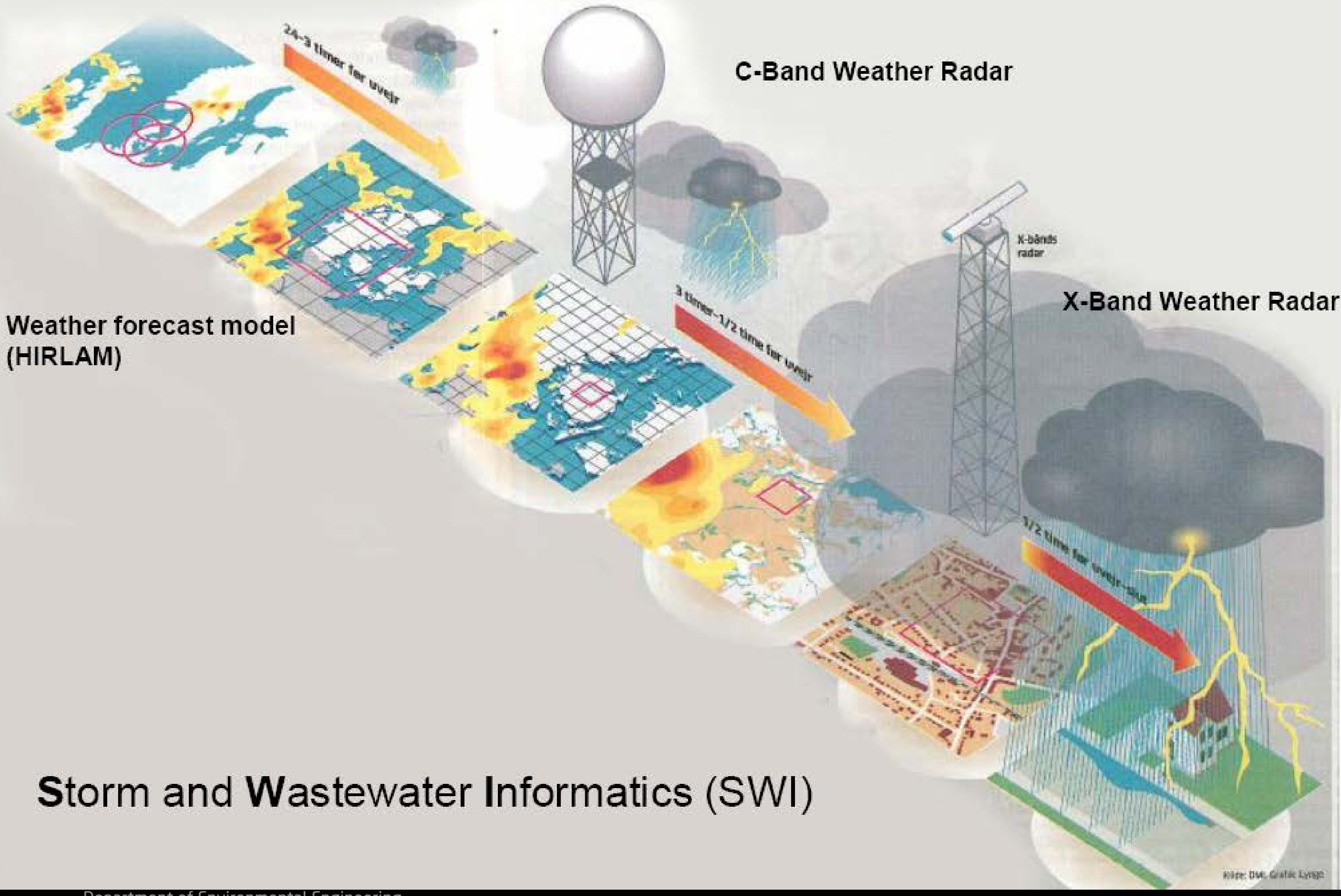
SWI Intelligence Inside

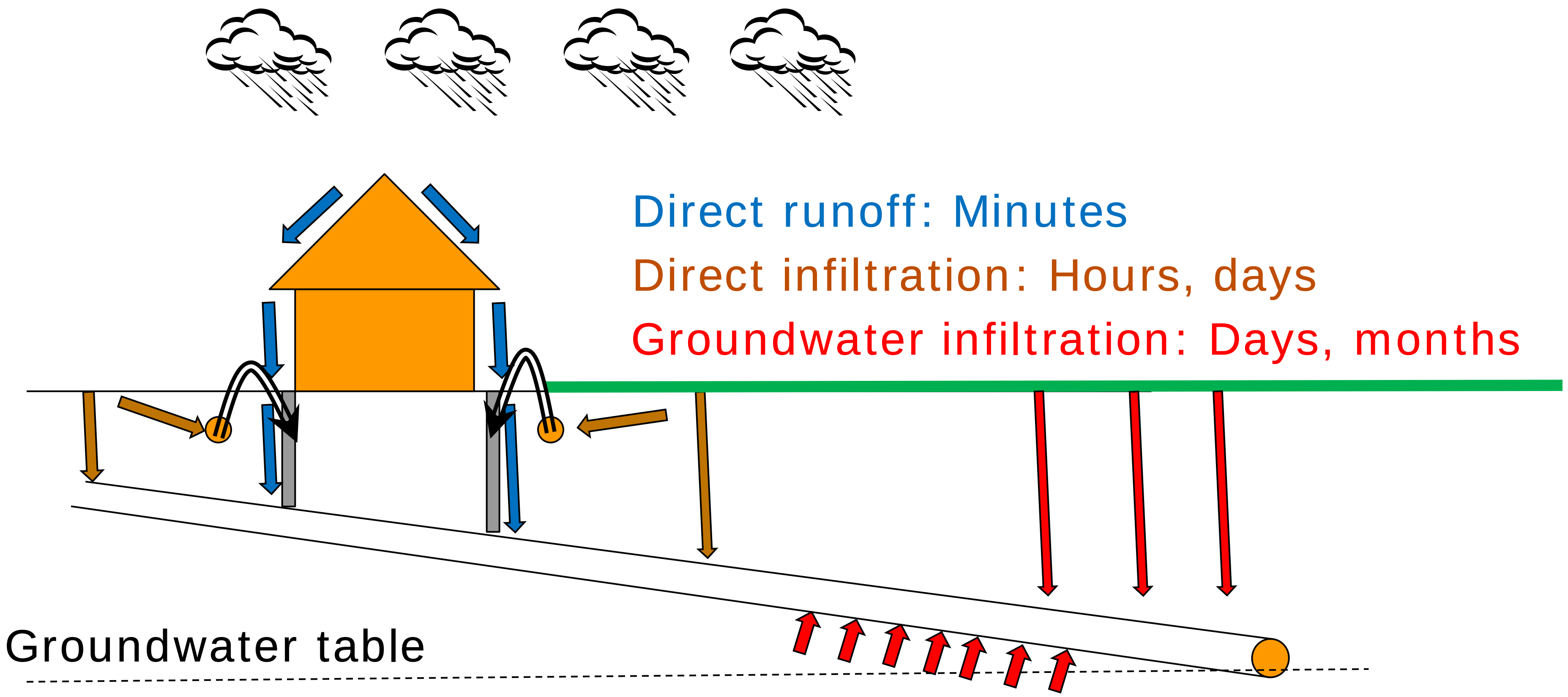



# **S**torm and **W**astewater **I**nformatics (SWI)

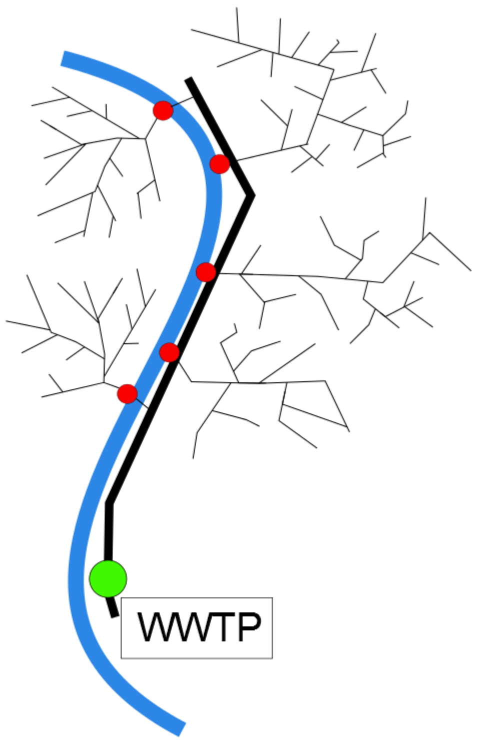
# Outline

- Urban drainage systems: Background
- Physically based, distributed urban drainage models and what they can do
- EnKF issues
- Small example

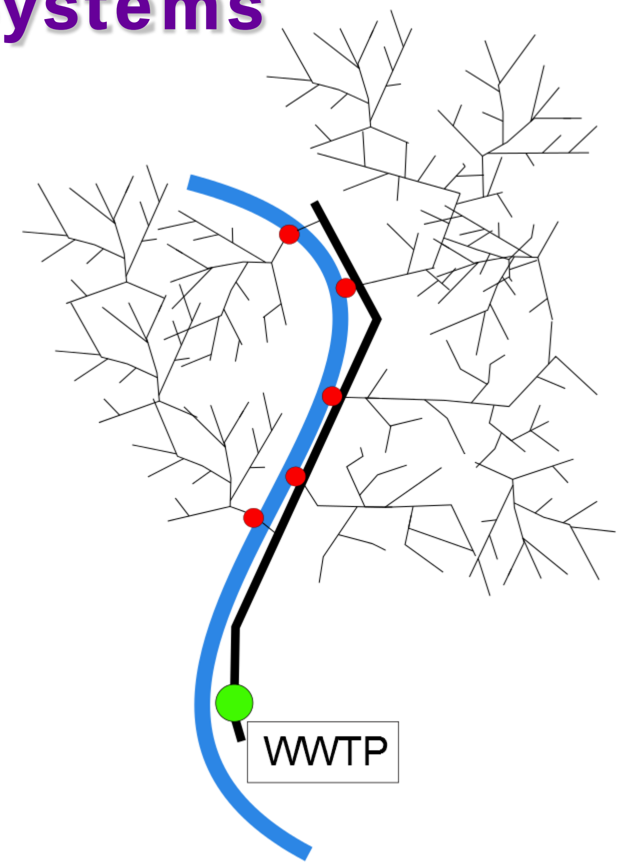
# Generating Urban runoff



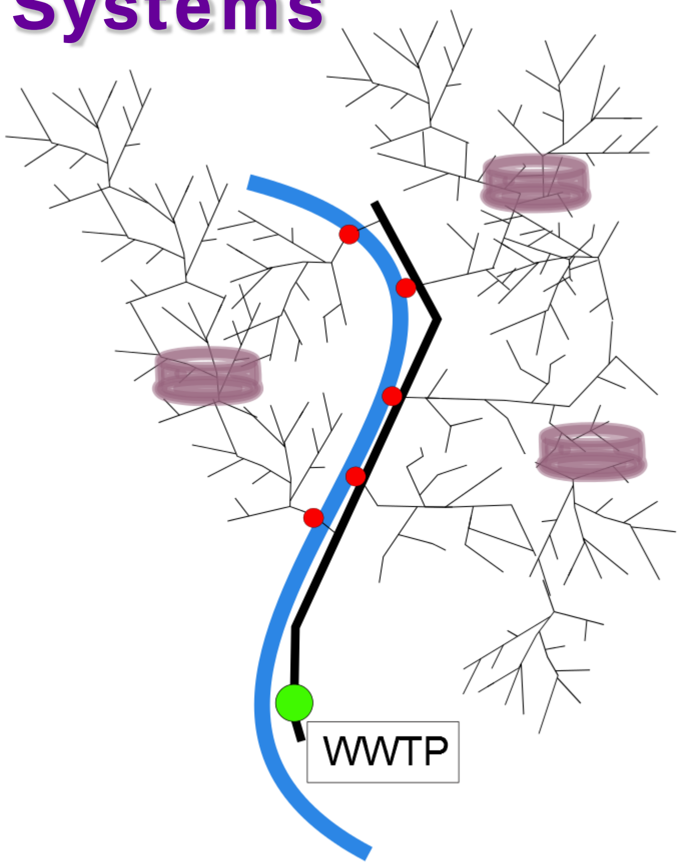
# Urban drainage Systems



# Urban drainage Systems

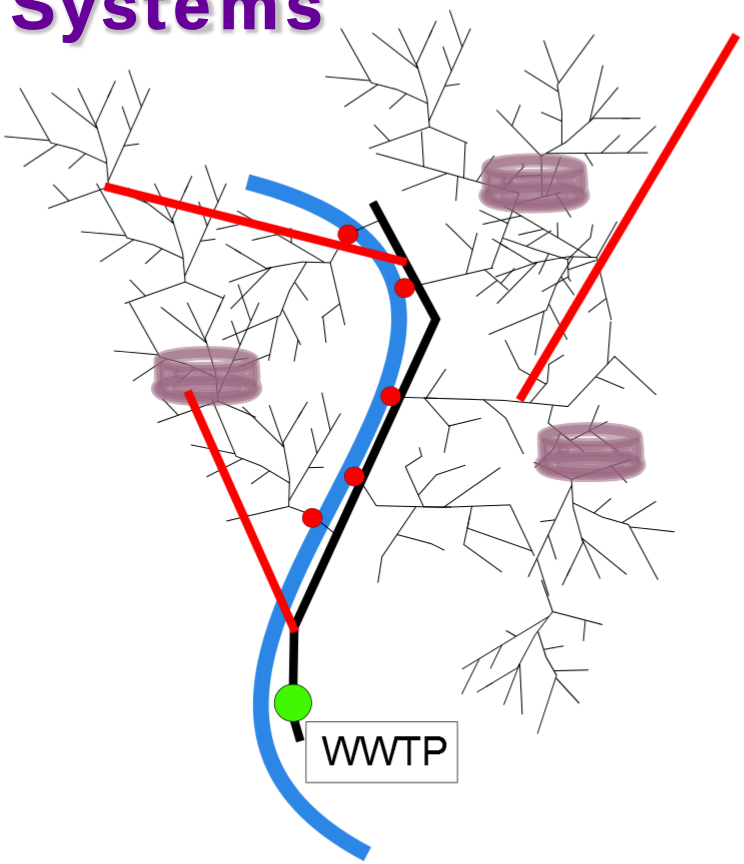


# Urban drainage Systems

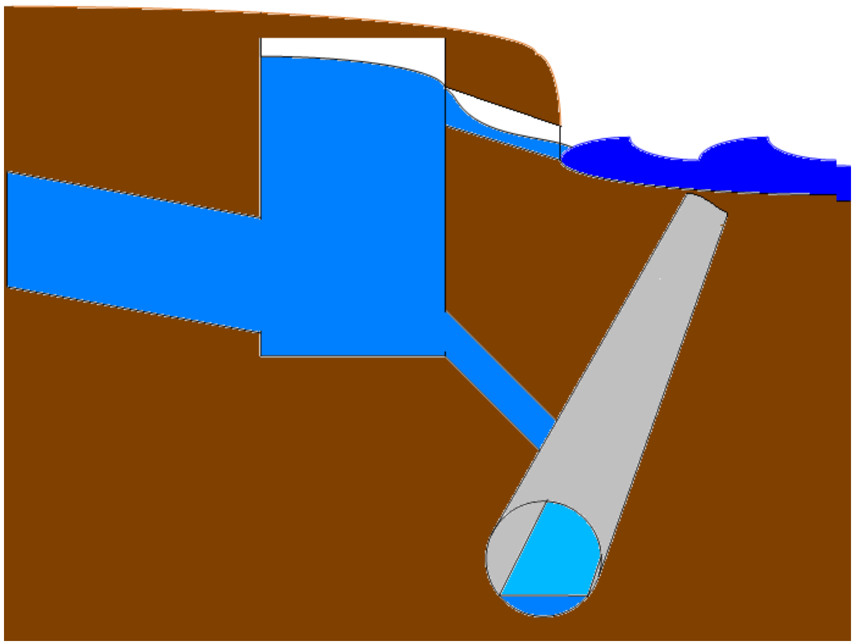


# Urban drainage Systems

- It's a mess
- Suboptimal for most events
- Control is needed



# Overflow structure

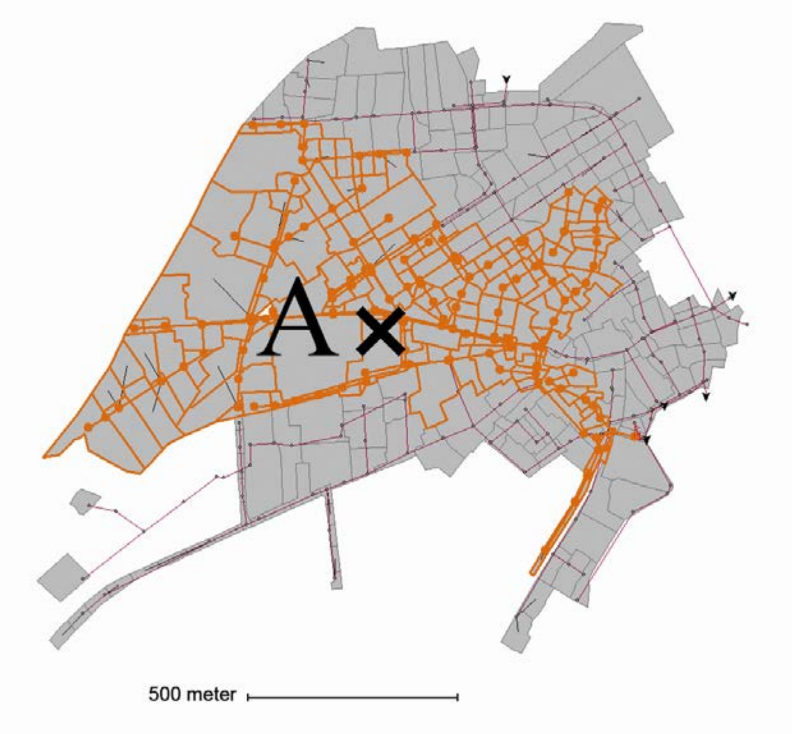


# Differences to other hydrological system

- Fast response times
- Closed conduits -> max. capacity
- Overflows: Water disappears out of system
- Real time control change hydraulic behaviour in seconds

# Distributed, physically based, urban drainage models

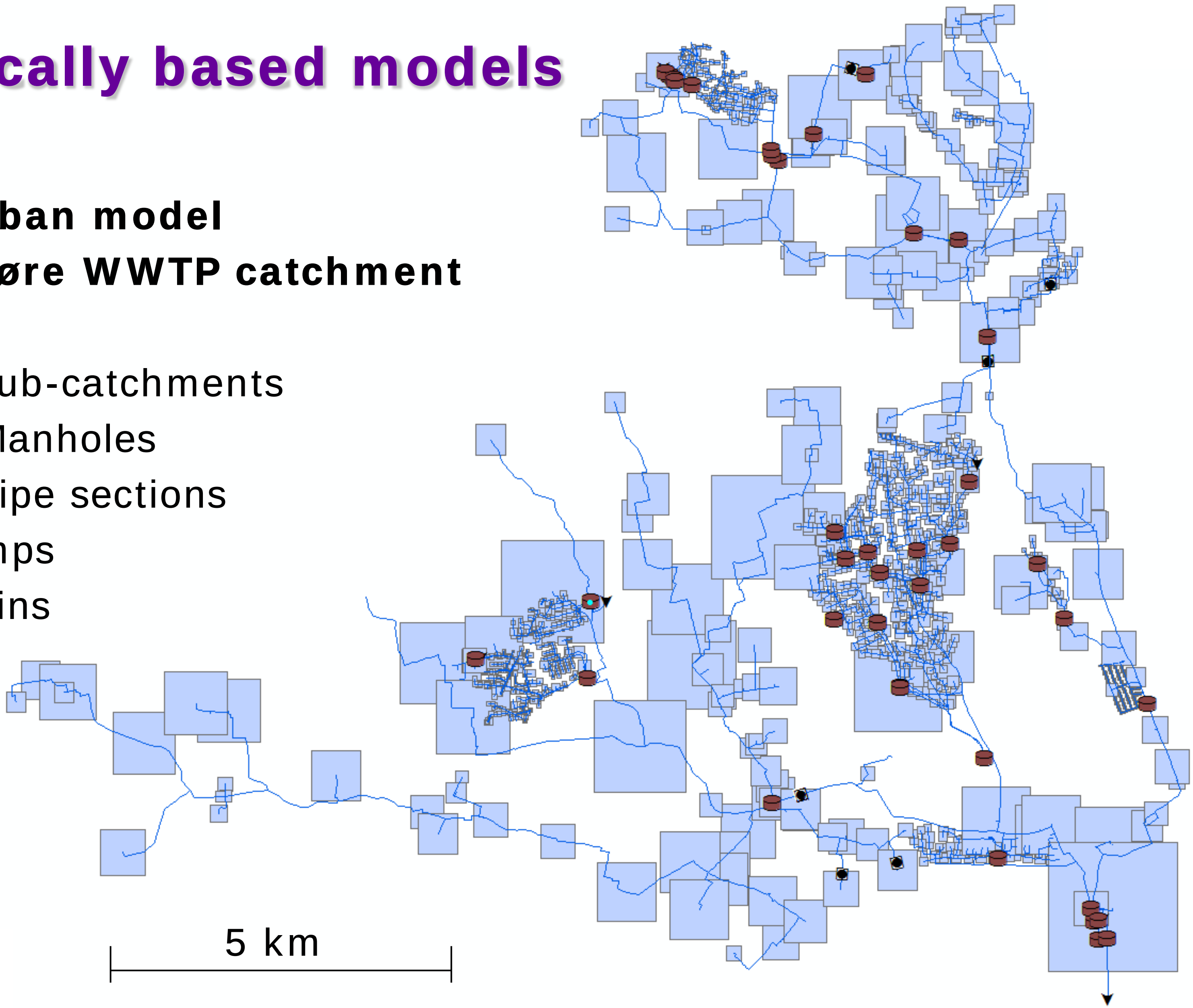
- Mixture of models: Runoff + Hydrodynamic + Water Quality
- Developed mainly for design purposes
- Can be build purely from physical data without calibration



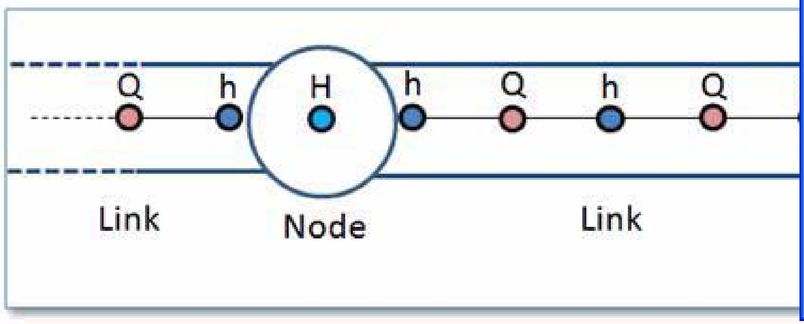
# Physically based models

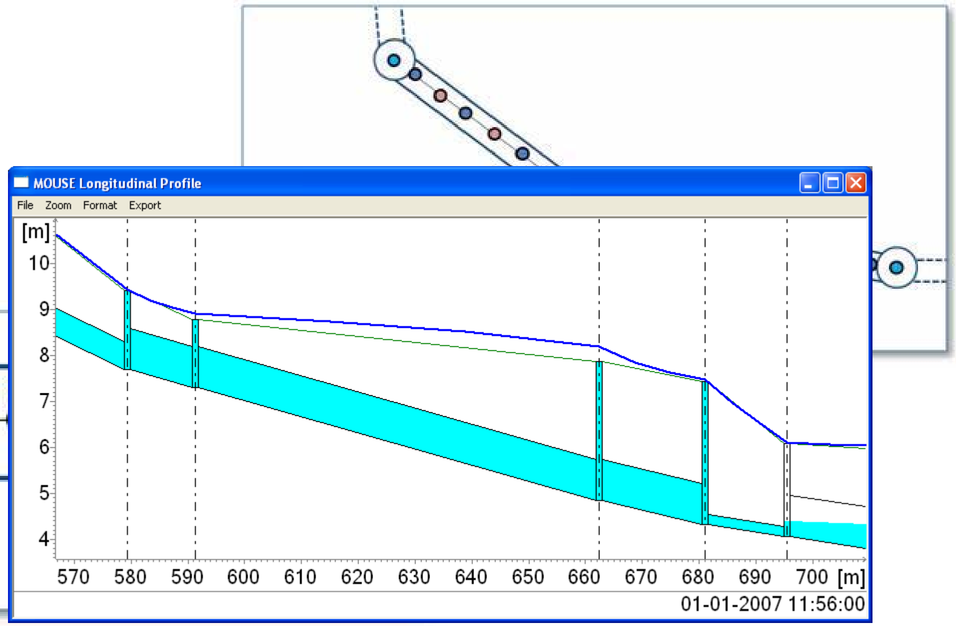
**Mike Urban model**
**of Avedøre WWTP catchment**

- 1707 sub-catchments
- 6601 Manholes
- 7749 Pipe sections
- 40 Pumps
- 40 Basins
- Etc.



# Pipe flow modelling




- Full 1D St. Venant equations

  Conservation of mass:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

  Conservation of momentum:

$$\frac{\partial Q}{\partial t} + \frac{\partial \left( \alpha \frac{Q^2}{A} \right)}{\partial x} + gA\frac{\partial y}{\partial x} + g\ AI_f = gAI_0$$

# Multi purpose model

- **Dimensioning** of new system elements
  - Max frequency of water on terrain, basements etc.
- Calculate **yearly overflow** and **pollution loads**
  - Documentation to authorities
- Develop and **optimize control** strategies
  - Both PID and model predictive control using simple models

**Are NOT used as online models**

# Purpose of online model

# Real time health risk assesment


København

Lyngbyvej

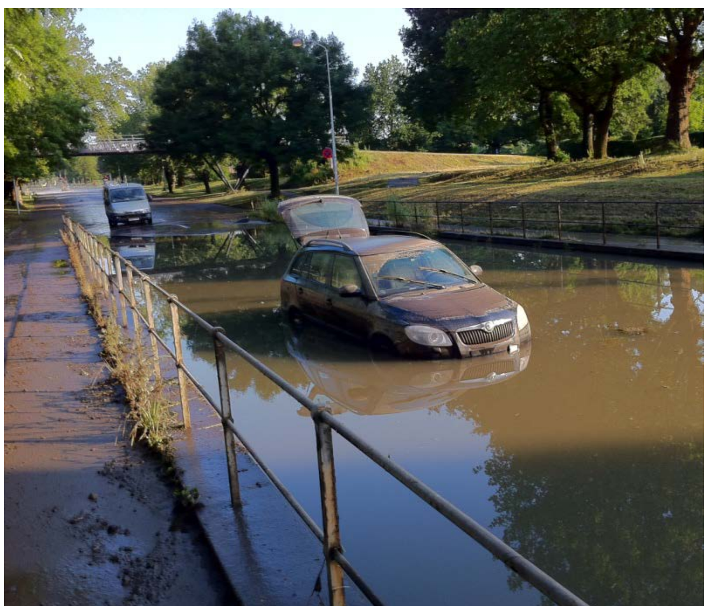
16 aug. 2010

Photo: Bente Schou

# Error detection!

# Model assisted real time control

- Aim:
  - reduce flooding
  - reduce or redirect overflow
  - Reduce cost of electricity consumption



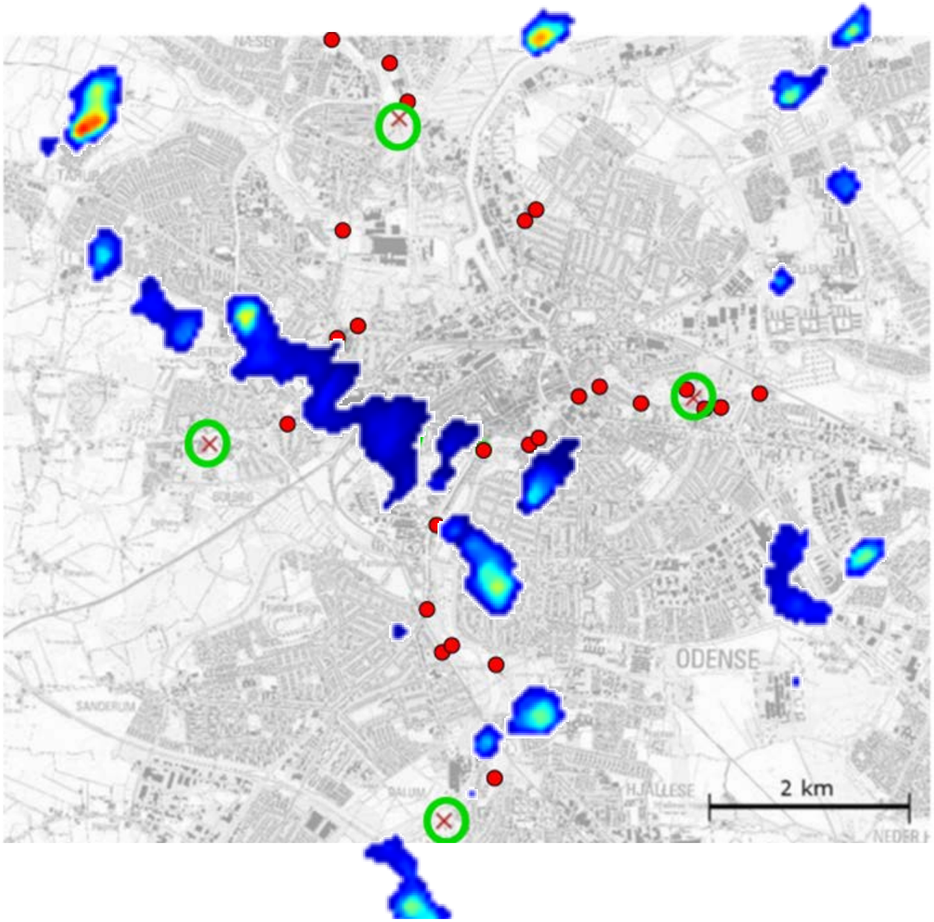
# Currently not used online because

- Computational cost – hardly run real time
- Very uncertain rain input
- No efficient update algorithm

# Ensemble based updating

# Dominating error source: Rain estimates

- Gauge:
  - Accurate in small area
  - -> huge ensemble required to represent spatial variability
- Radar
  - Very inaccurate short term rain depth
  - But spatial information -> reduced ensemble size



# Q Update

# Q changes makes no lasting change

- Q update do not change the volume of water in an area and thus the change is only local and temporary.

Full 1D St. Venant equations

Conservation of mass:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

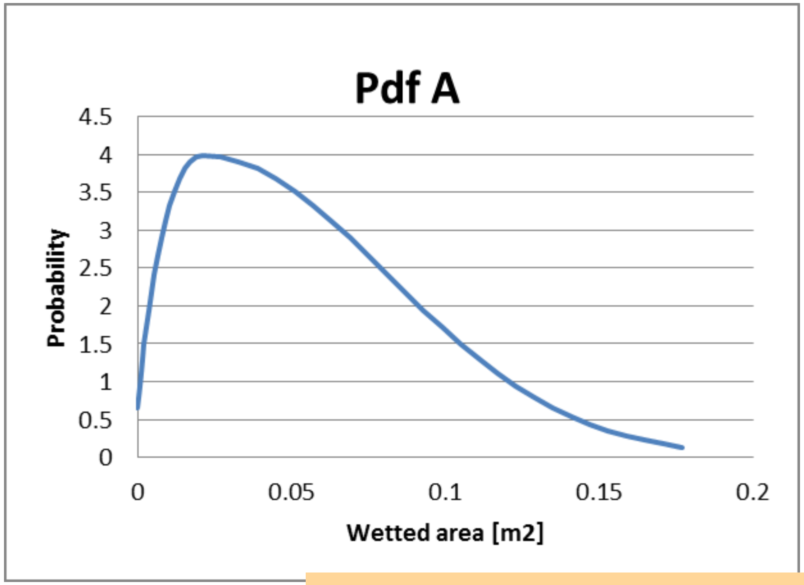
Conservation of momentum:

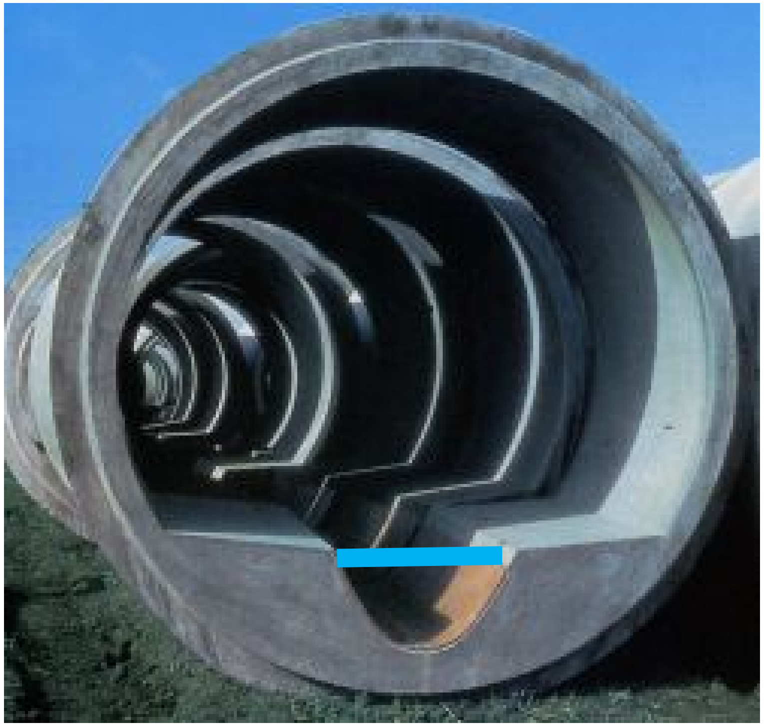
$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial y}{\partial x} + g\,AI_f = gAI_0$$

# H update

# Overestimated observation variance

- Change in volume per change in h is depth dependent.

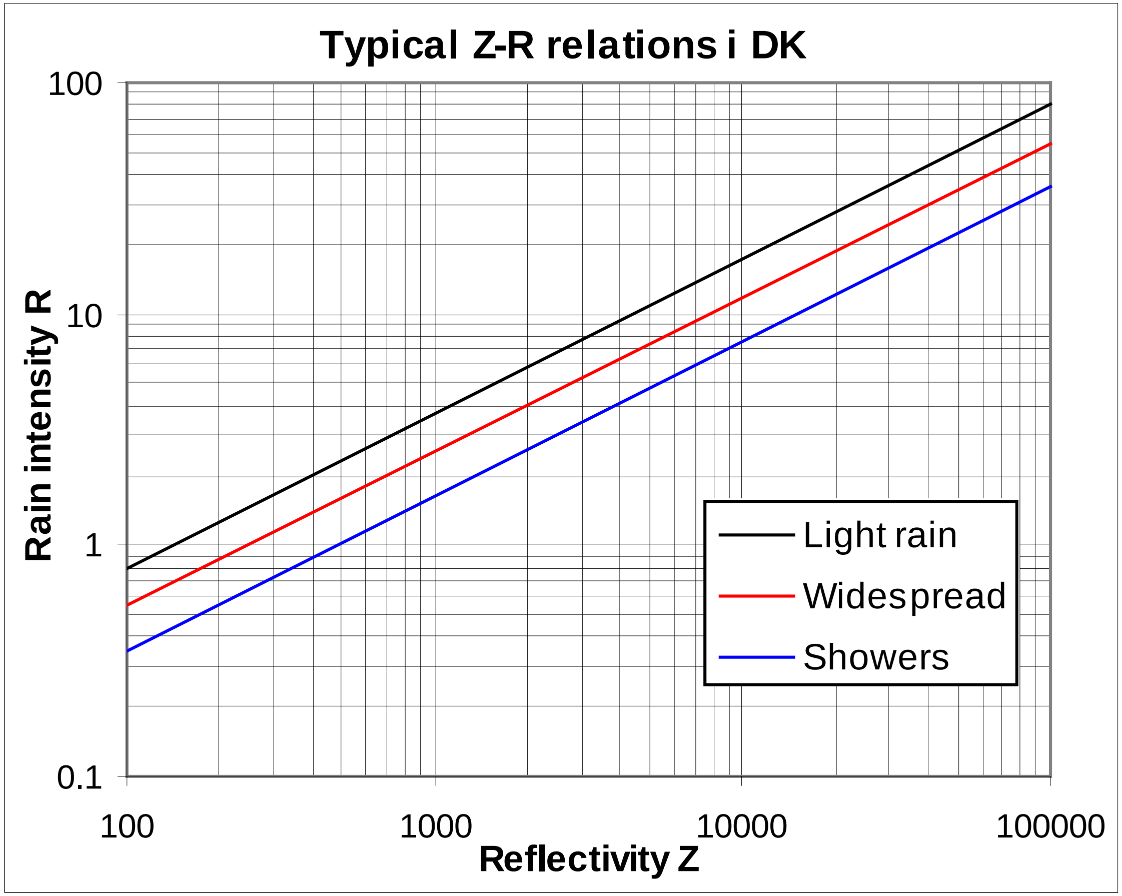


**-> avoid perturbated observations**

# EnKF Example using constructed radar data

# Radar data



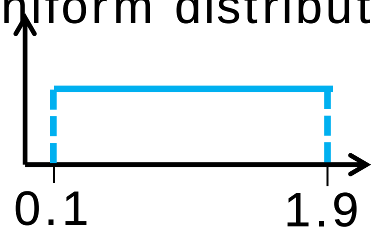
Typical Z-R relations i DK
Rain intensity R
100
10
1
0.1
100
1000
10000
100000
Reflectivity Z
Light rain
Widespread
Showers

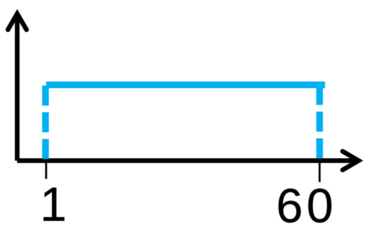
# Radar rain perturbation

- Assuming radar rain estimates
  - Assuming factorial error (Wrong guess at Marshall Palmers)
  - Assuming constant error factor in intervals

$$Estimated\ rain = \ actual\ rain * f$$

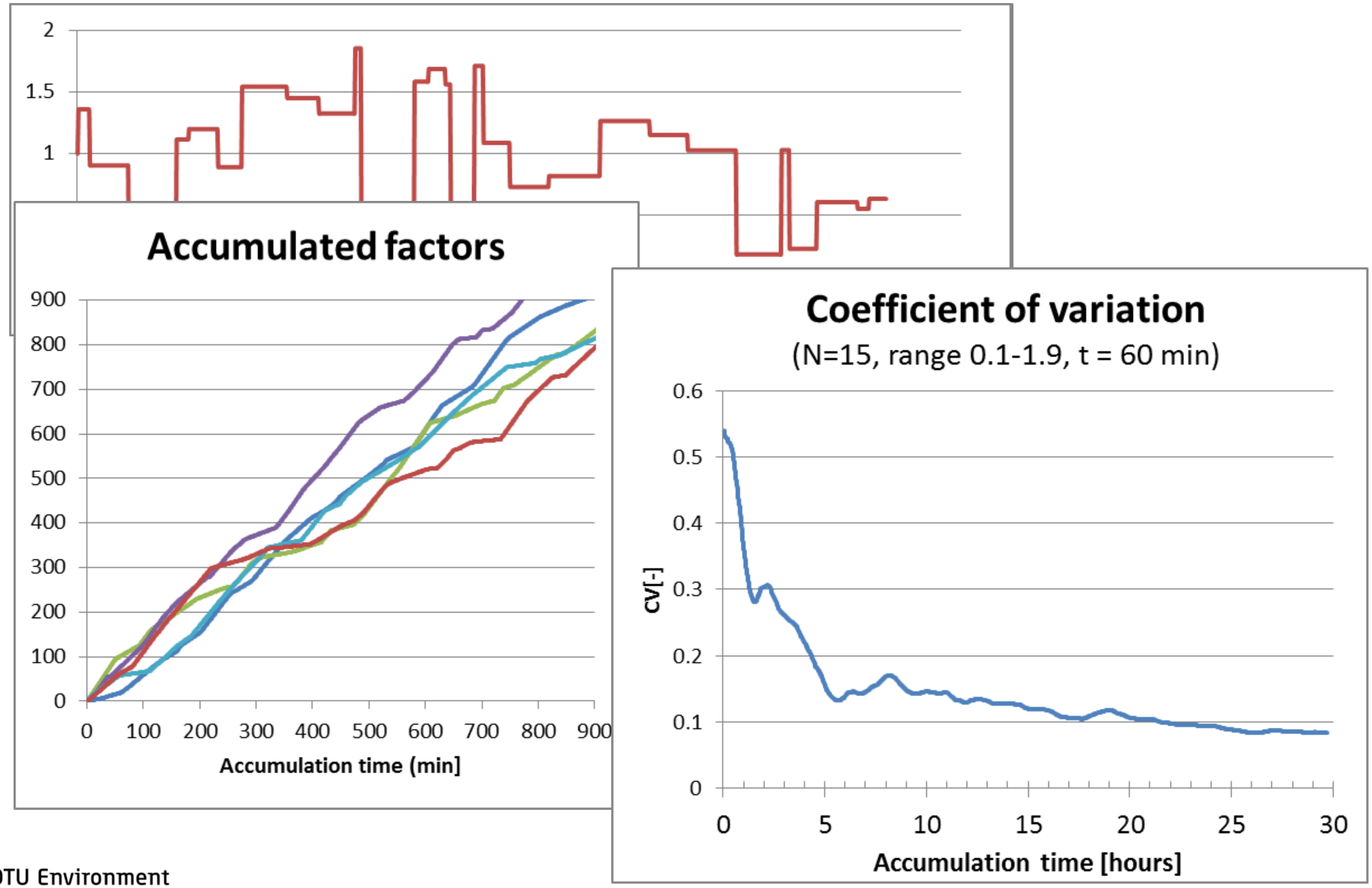
$f$ is drawn from uniform distribution *unif*(0.1, 1.9) every t minutes.



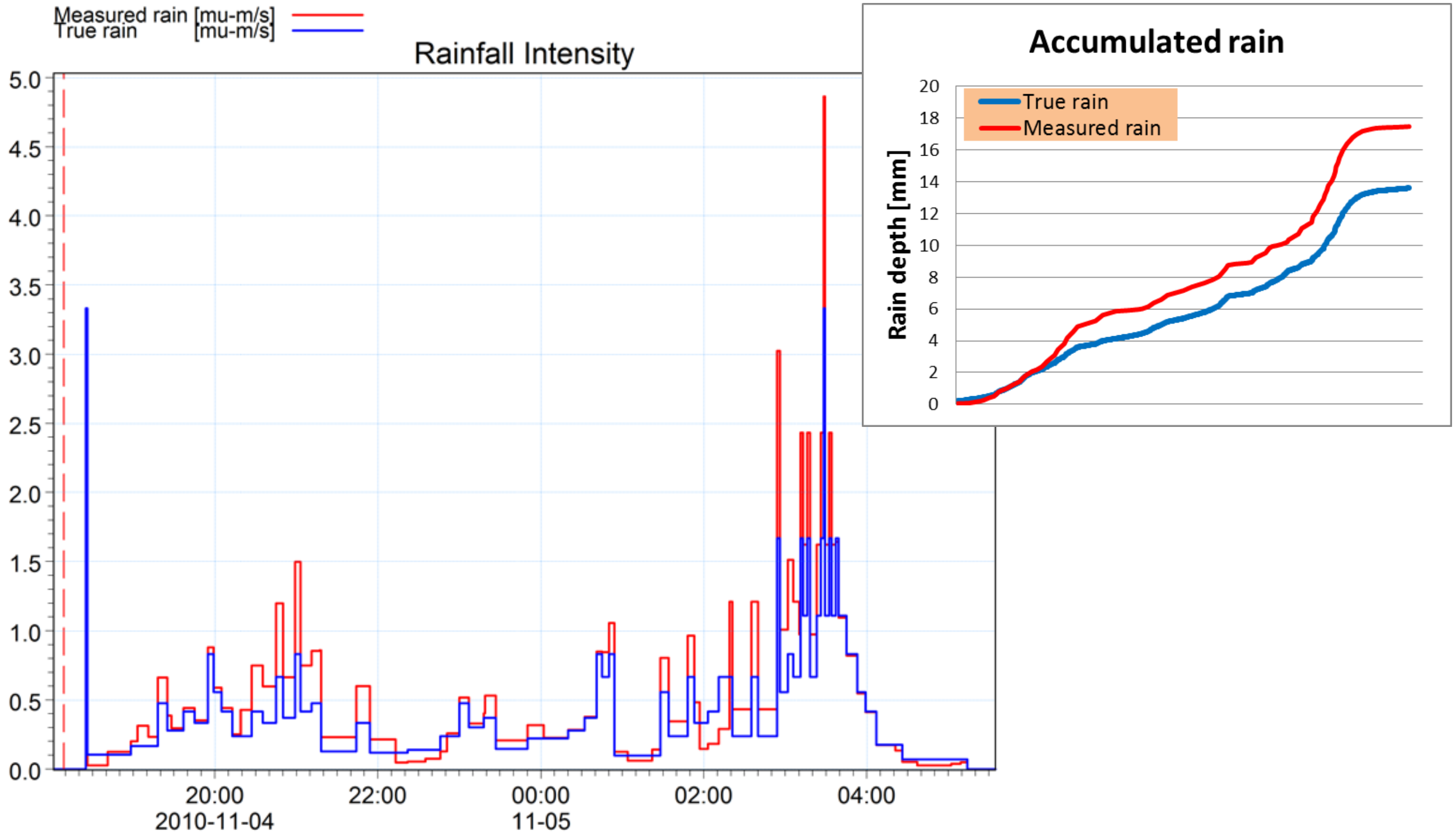




t is drawn from *unif*(1, 60) every t minutes.

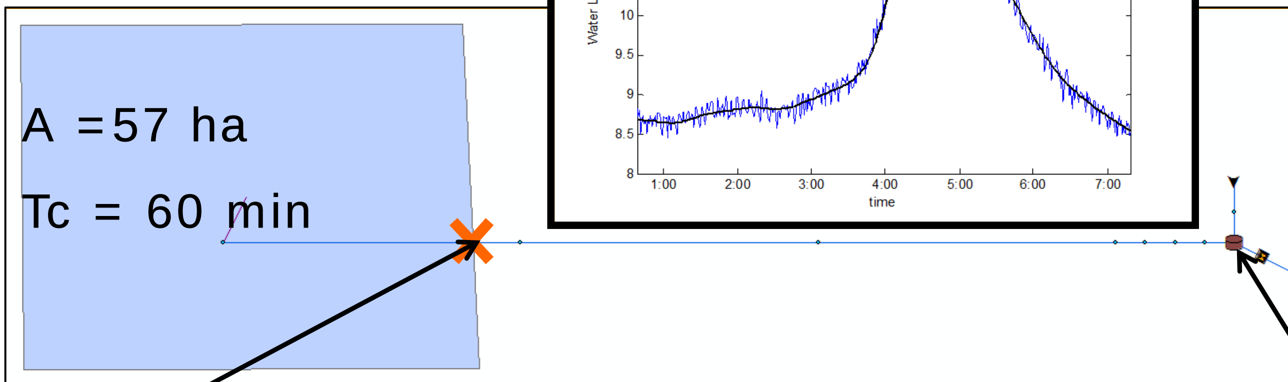
# Realization of f

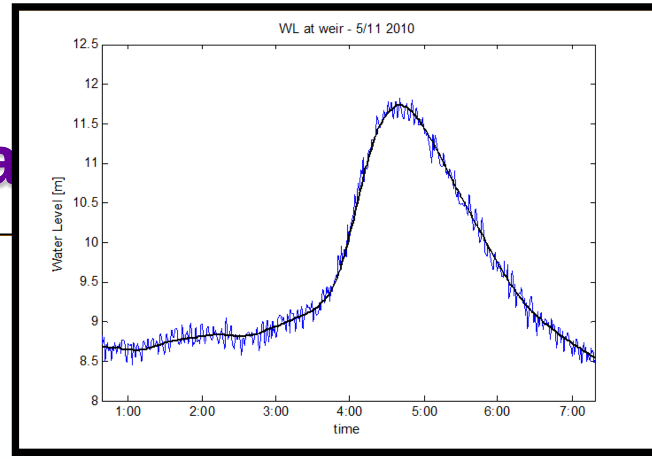


# Constructed radar estimate



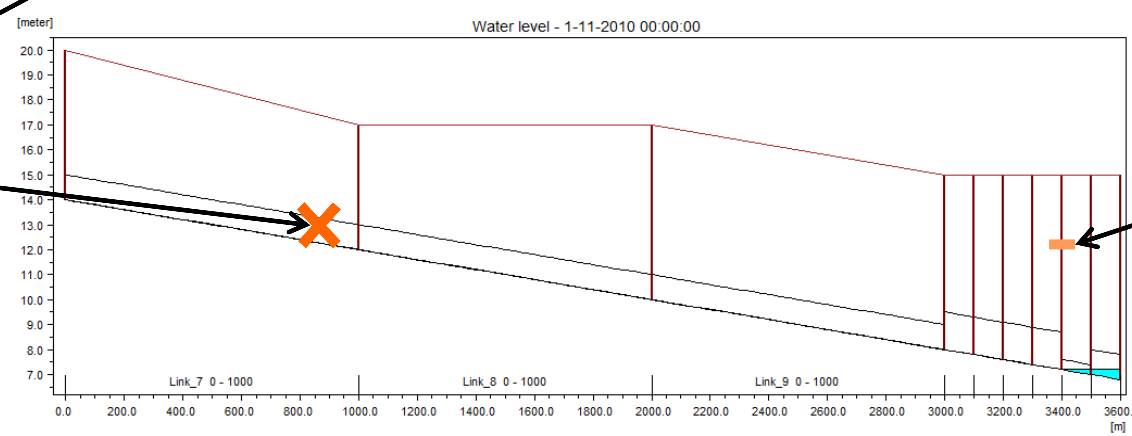
# Model setup: Link a



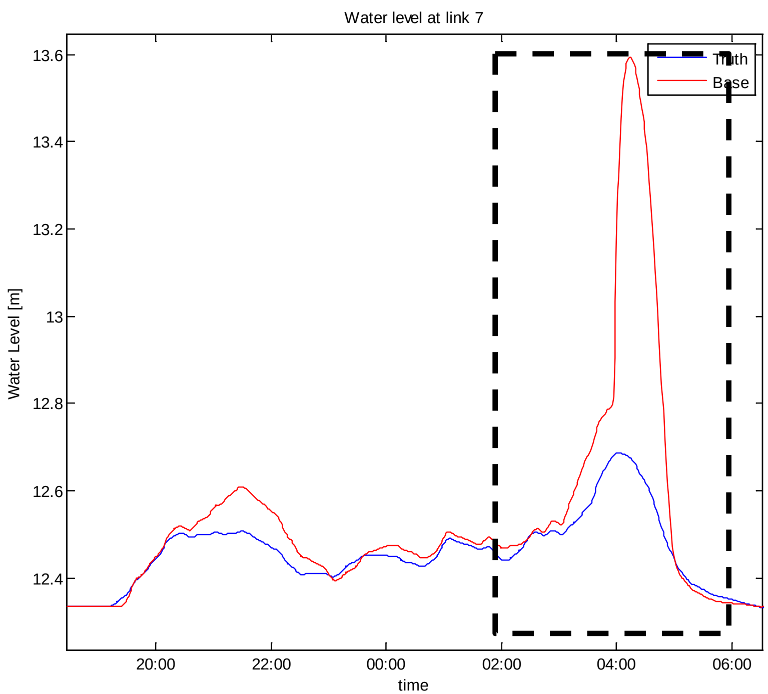

Point at Link 7

Weir



# Situation without update

Link 7

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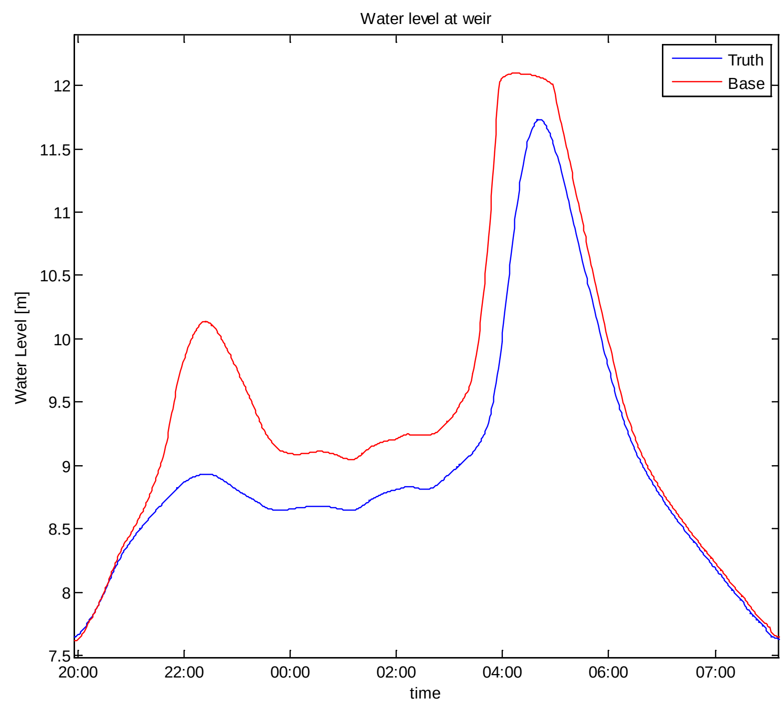
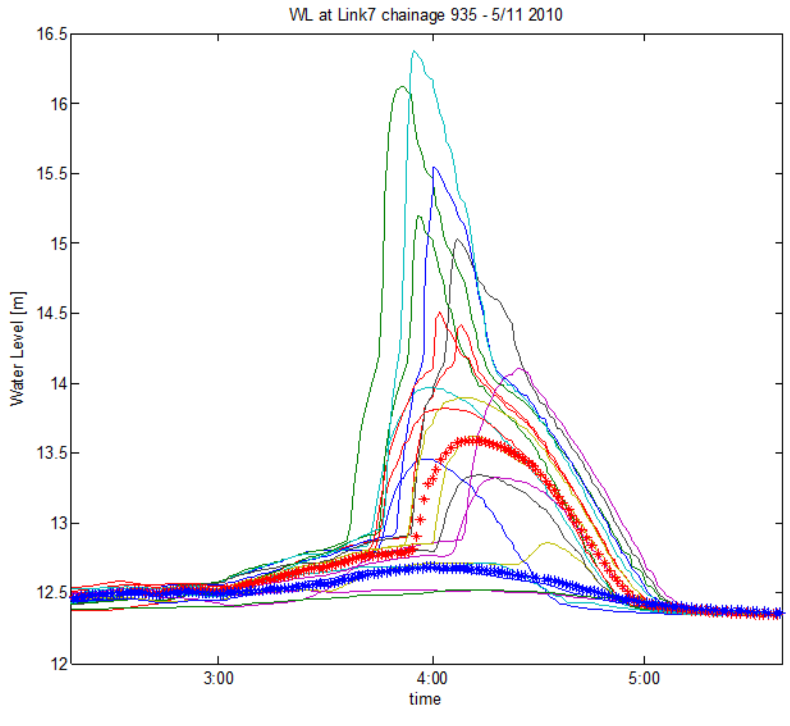


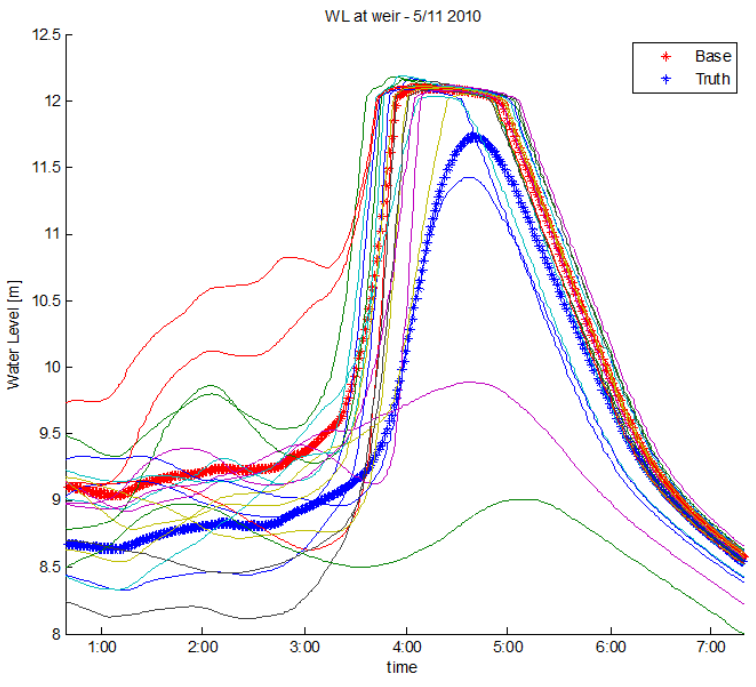
# Situation without update

Ensemble of 20 – No update

Link 7

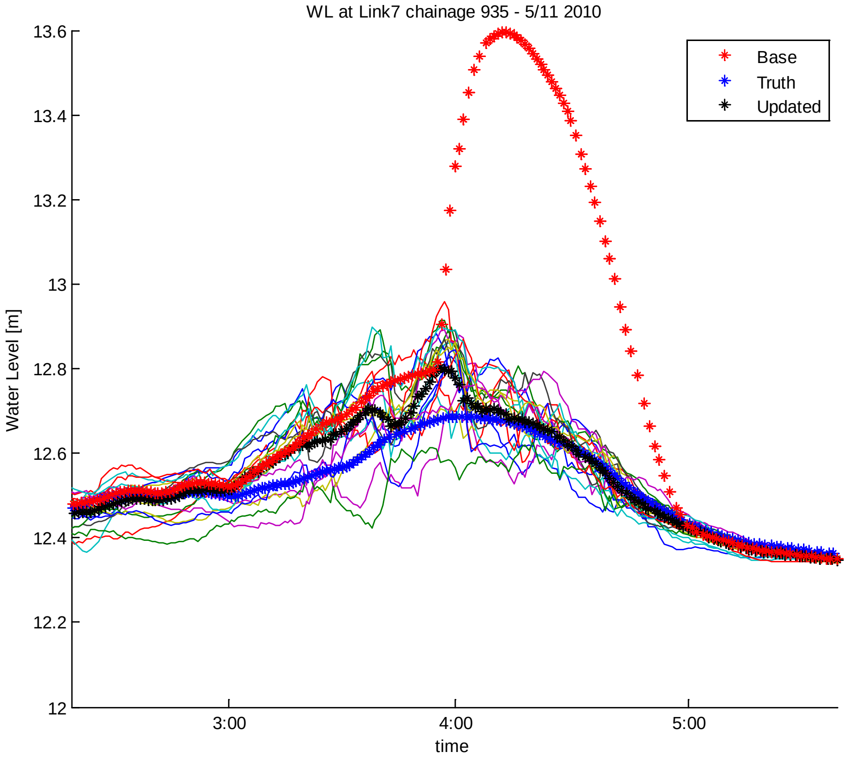
Weir



# When updating using EnKF

Link 7

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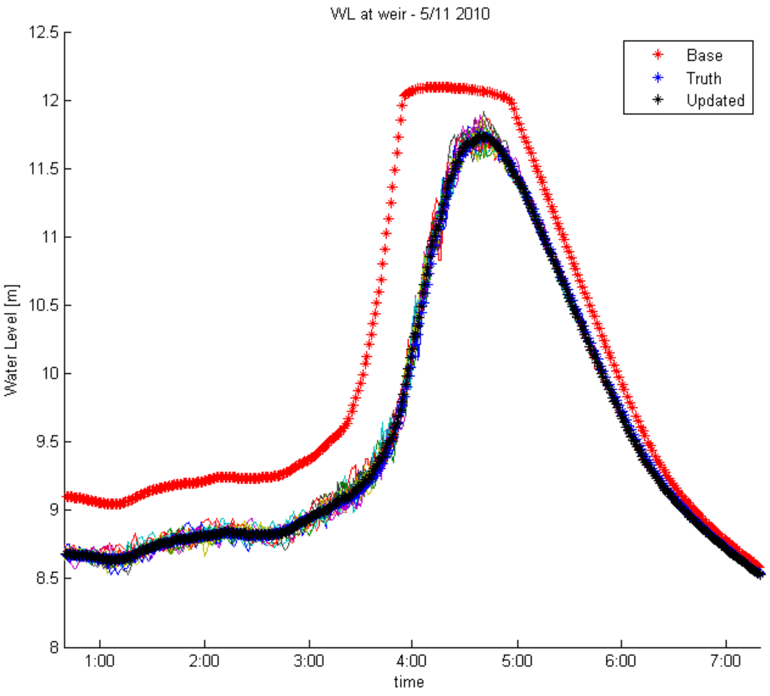
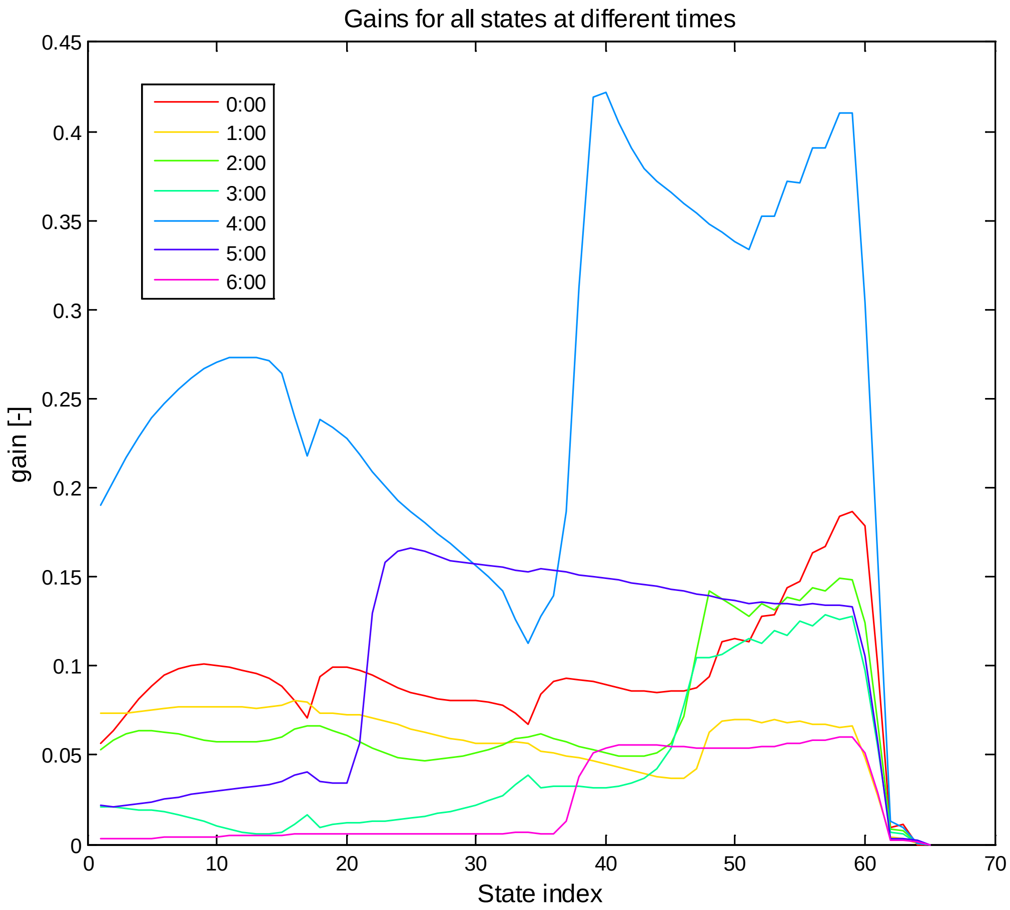
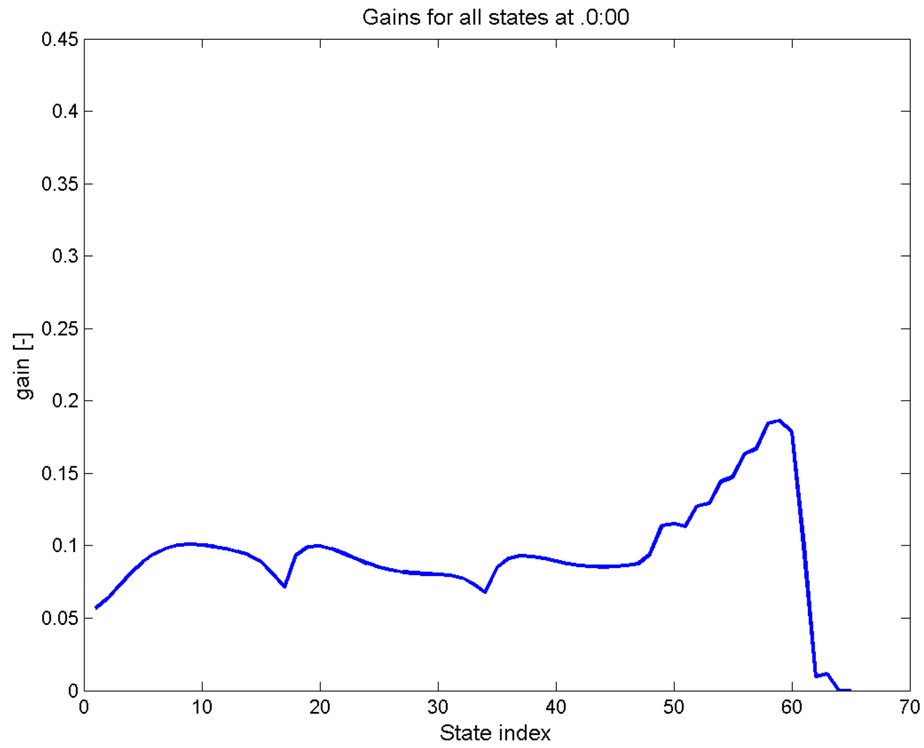


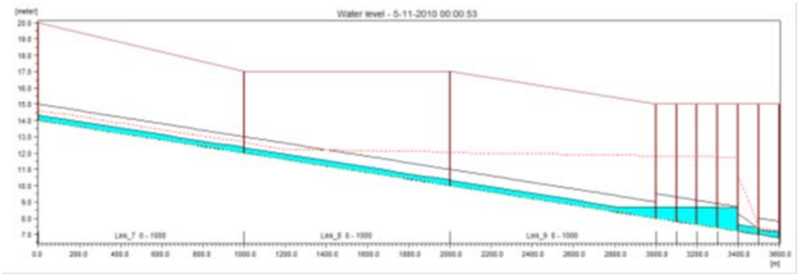
# Gain and backwater



# Calculated gain

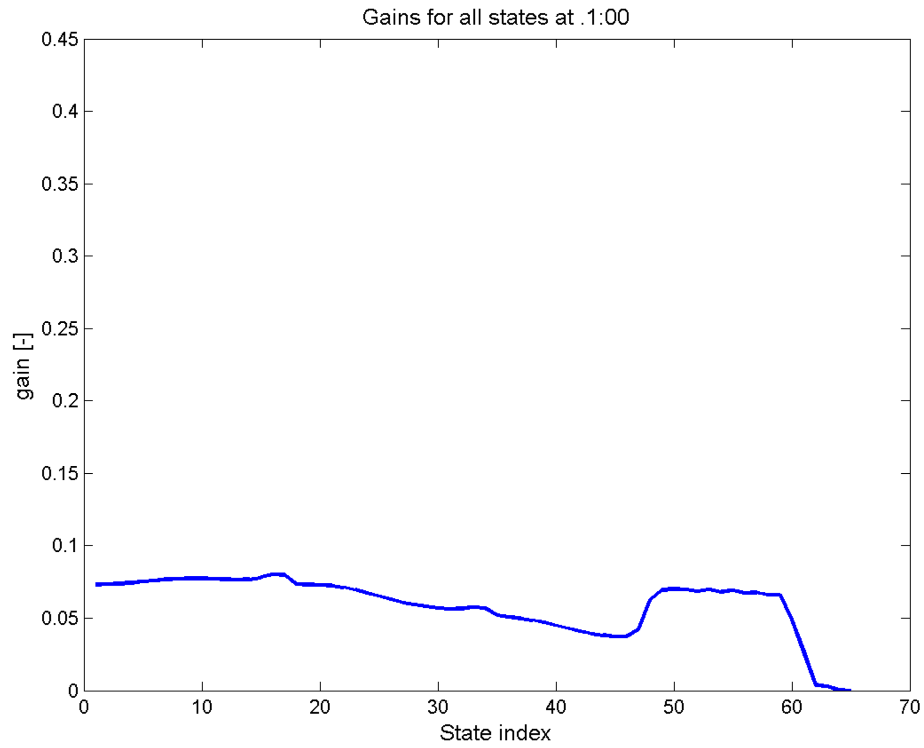
0:00

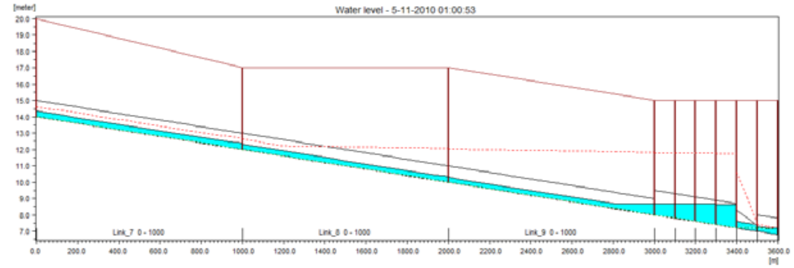


# Calculated gain

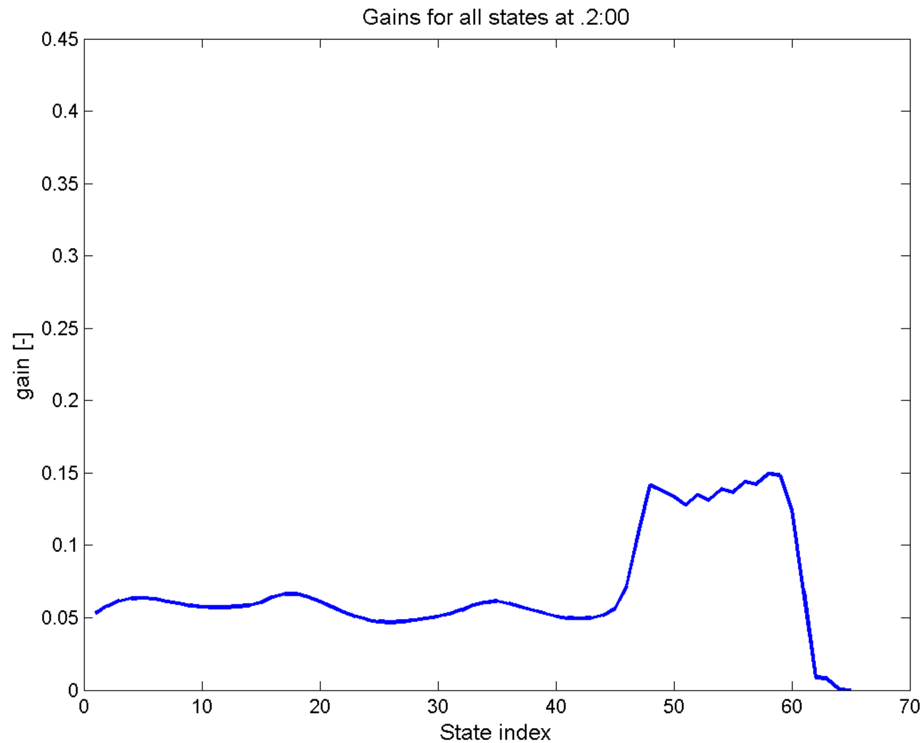
1:00

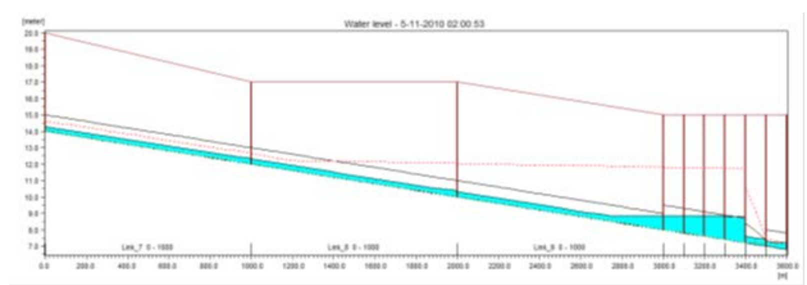


# Calculated gain

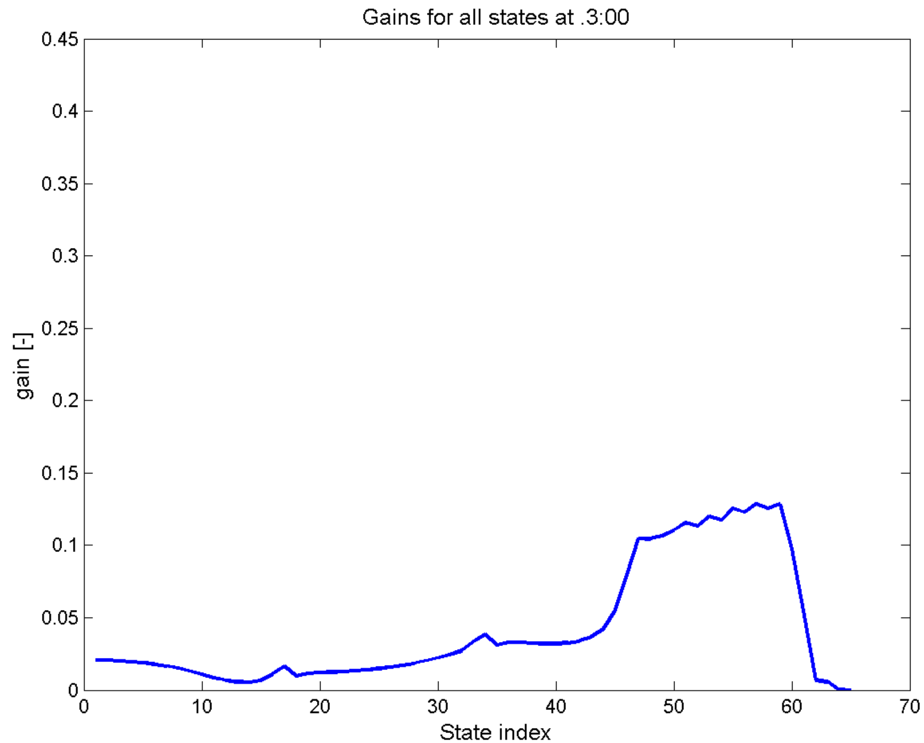
2:00

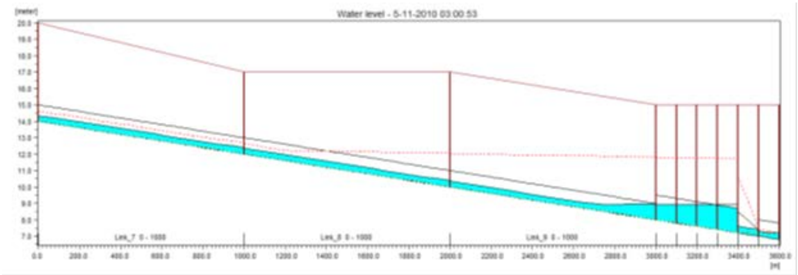


# Calculated gain

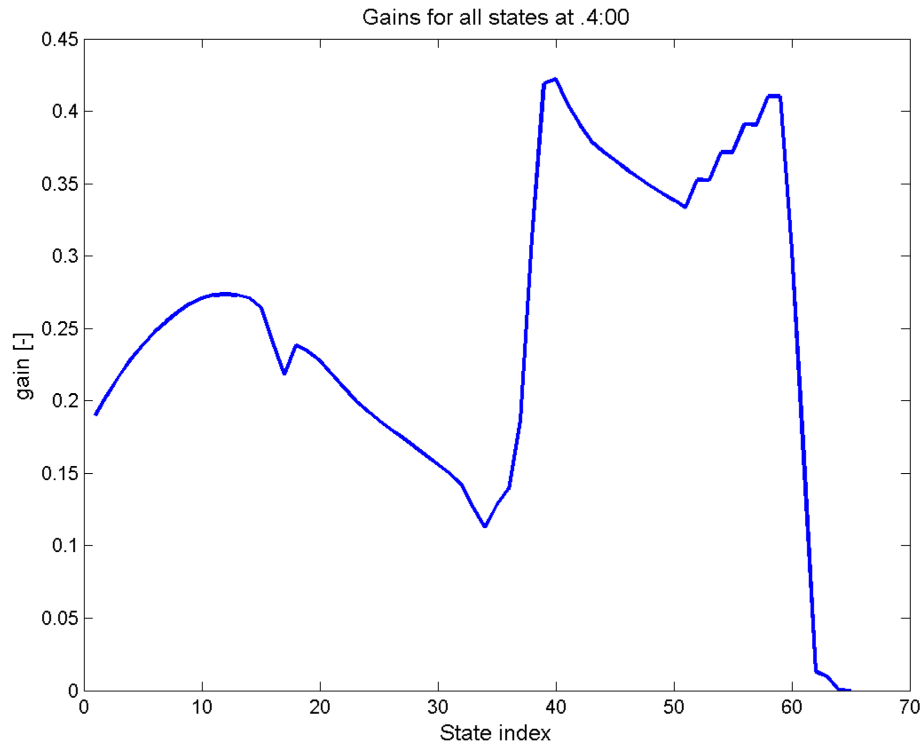
3:00

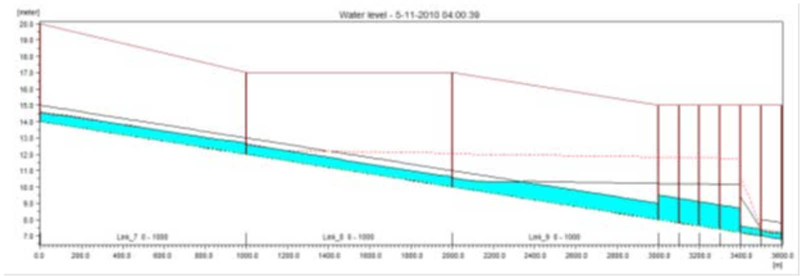


# Calculated gain

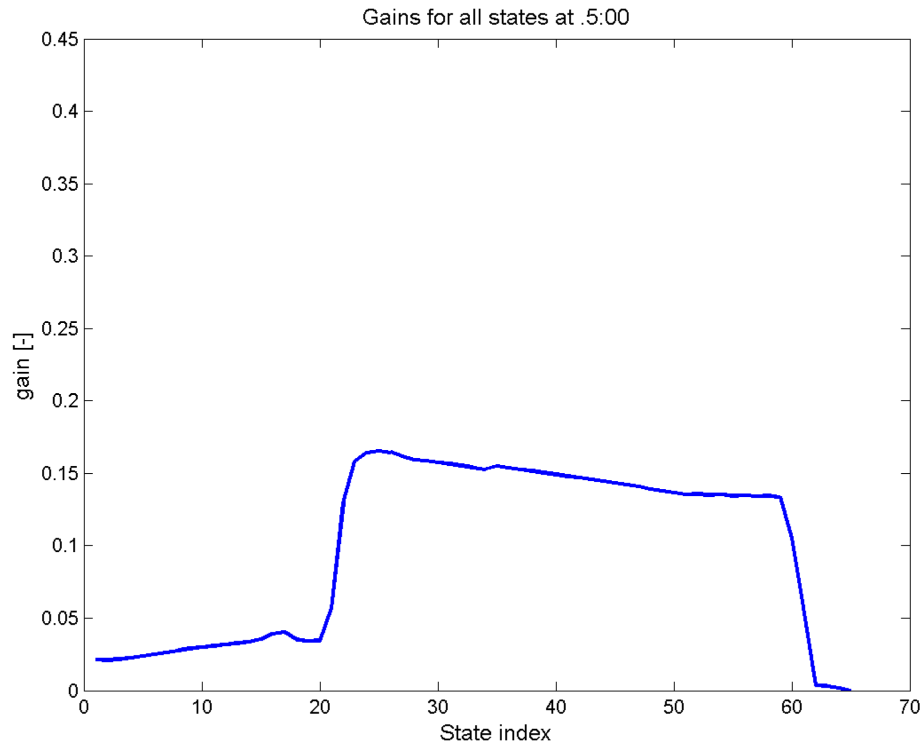
4:00

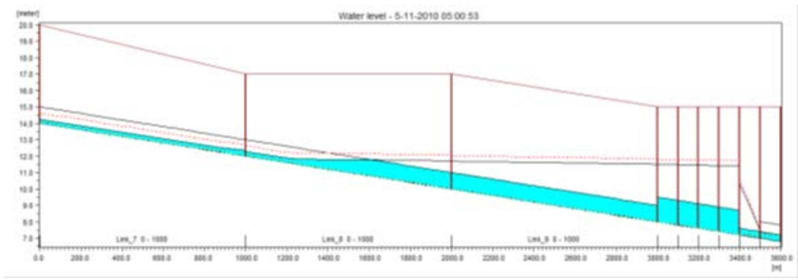


# Calculated gain

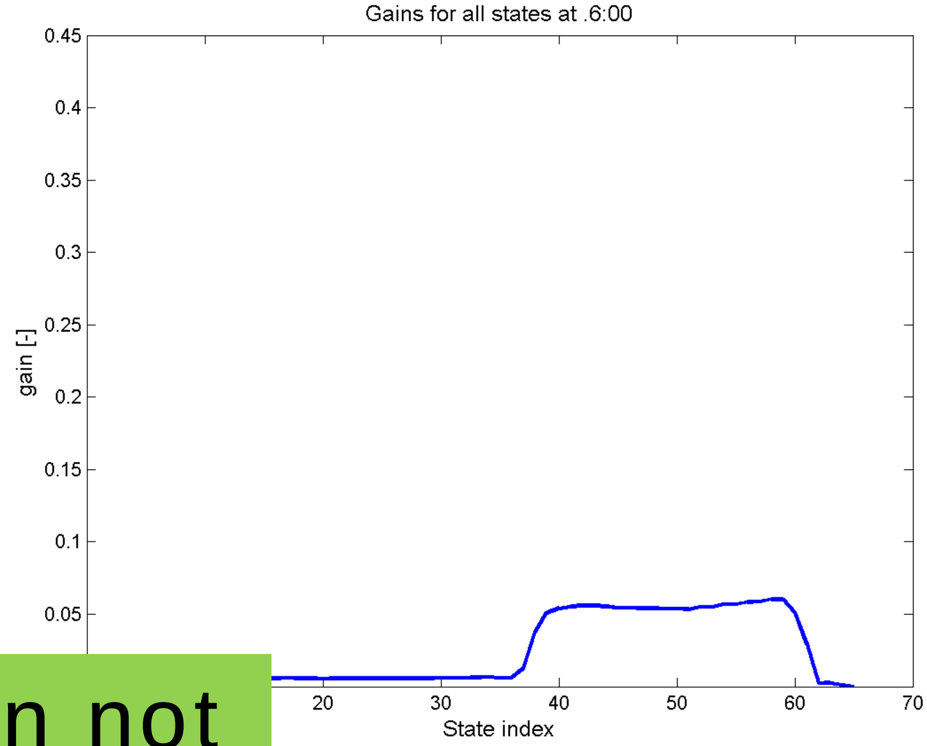
5:00



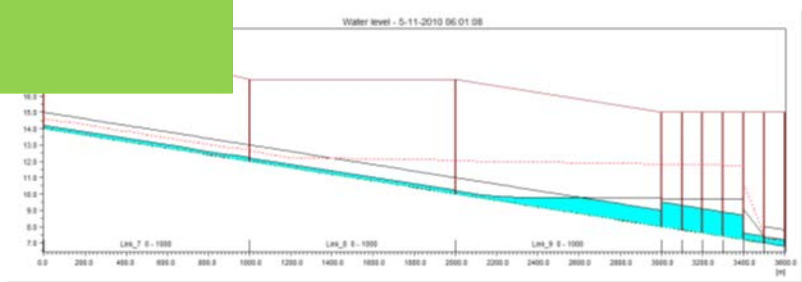



# Calculated gain

6:00

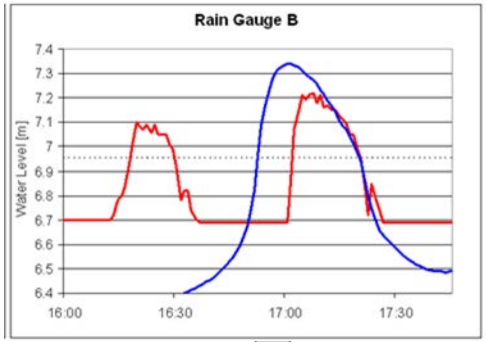


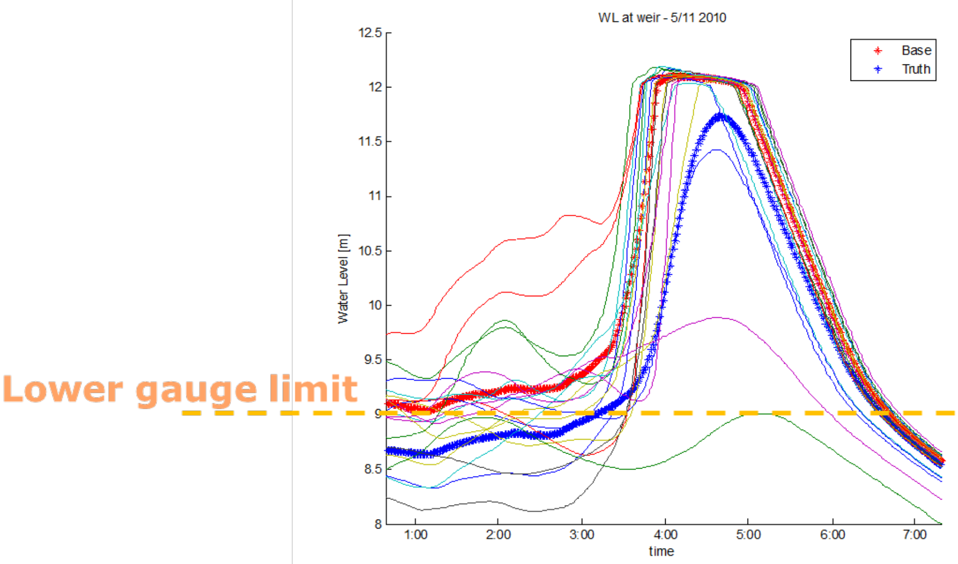

Constant gain not an option

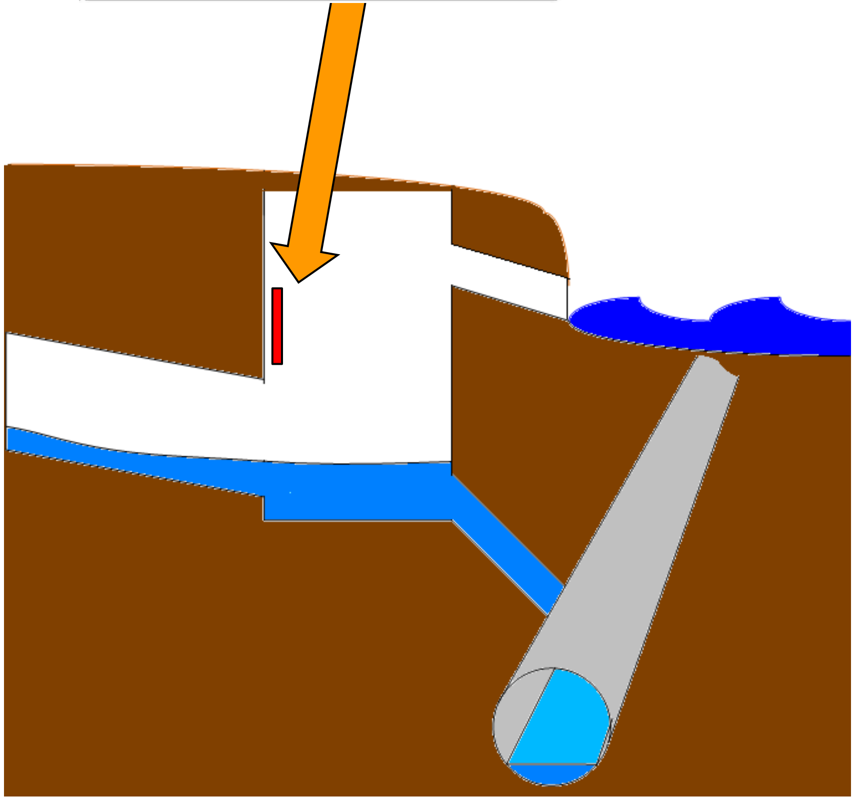


# Non measurements

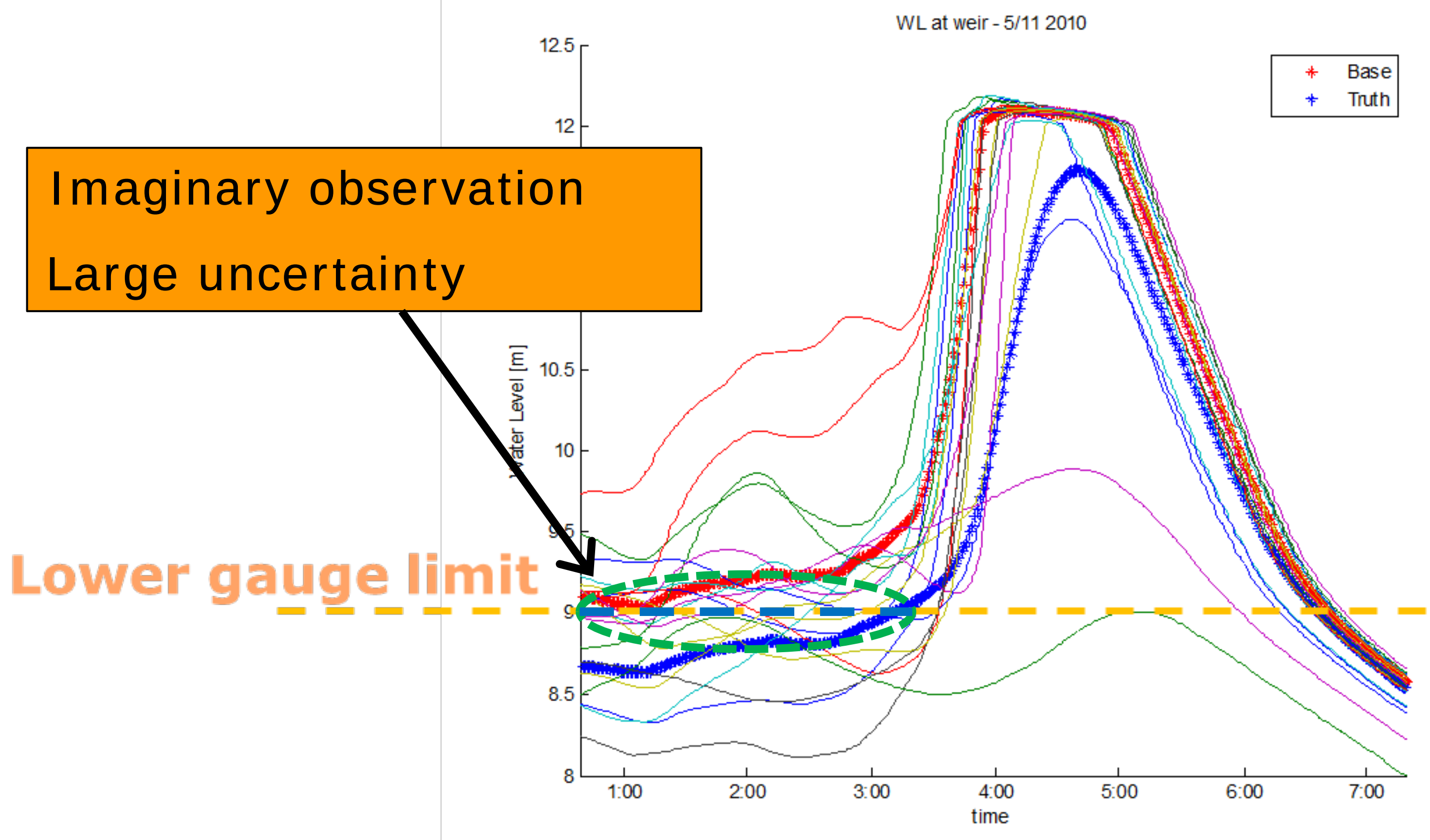
# WL gauge at weir



# Partial ensemble updating



# Partial DEnKF when no data

*Modified from [Sakov, 2008][1]:*

$$\mathrm{d}y = gaugeLimit - Hx^f$$

$$x^f = mean\left(X^f\right)$$

$$A^f = X^f - [x^f, .., .., .., x^f]$$

$$A^a = A^f - \tfrac{1}{2}KHA^fB$$

B = Diagonal matrix. 1 where $HA_i >= dy$, otherwise 0

$$X^a = A^a + \left[x^f, .., .., .., x^f\right]$$

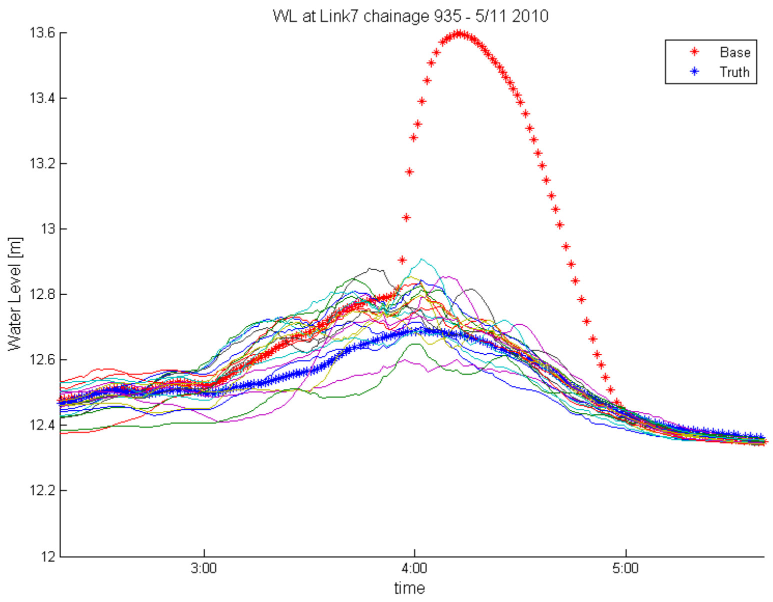
$$x^a = median(X^a)$$

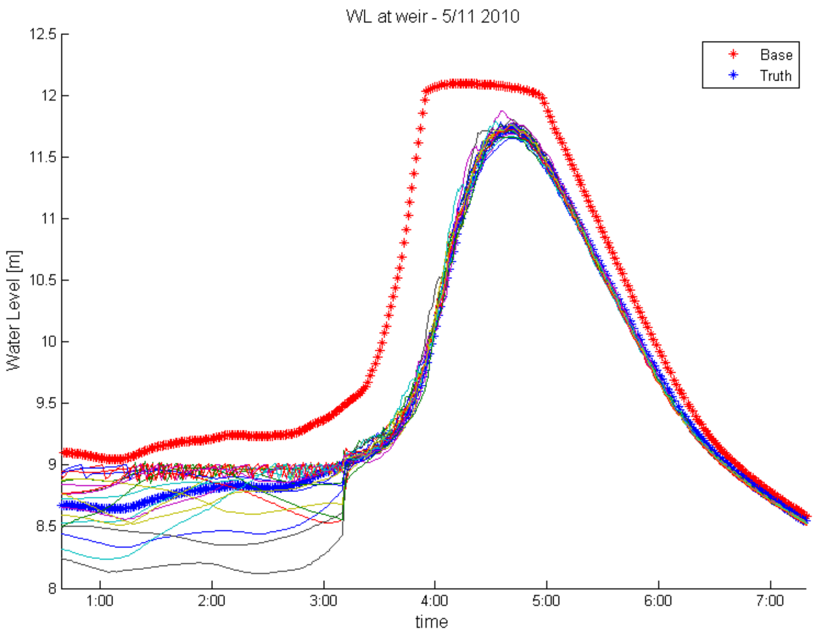


1) Sakov, P., & Oke, P. R. (2008). A deterministic formulation of the ensemble Kalman filter: an alternative to ensemble square root filters. *Tellus A*, *60*(2), 361–371.

# Partial DEnKF when no data

Example



# Summary

- Static gain not sufficient
- Radar data is almost a requirement for EnKF
- Ensemble spread can be reduced in periods without measurement
- Probably best to avoid perturbed observations

# Questions ?