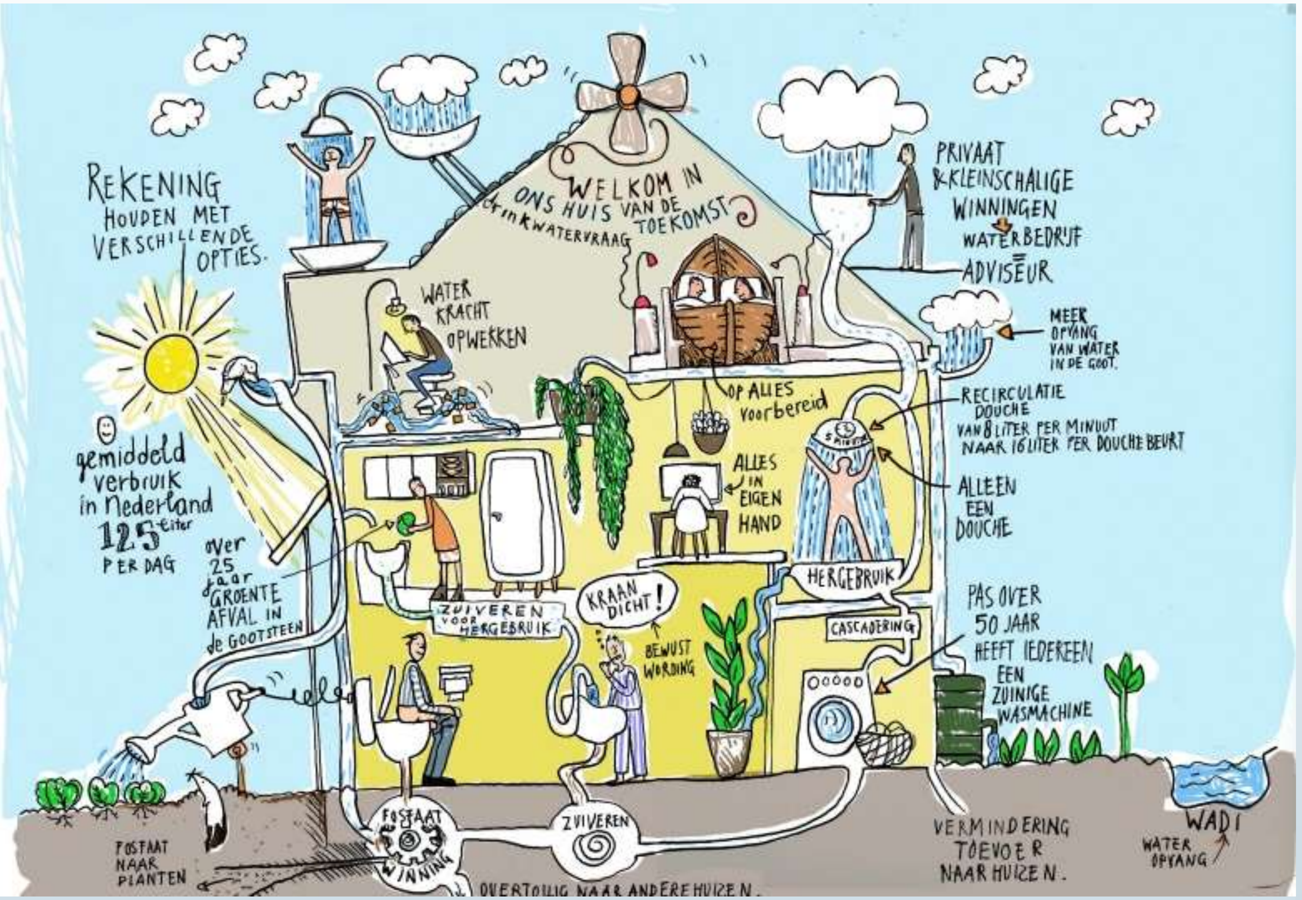
Water demand modelling: The key to understanding the water cycle

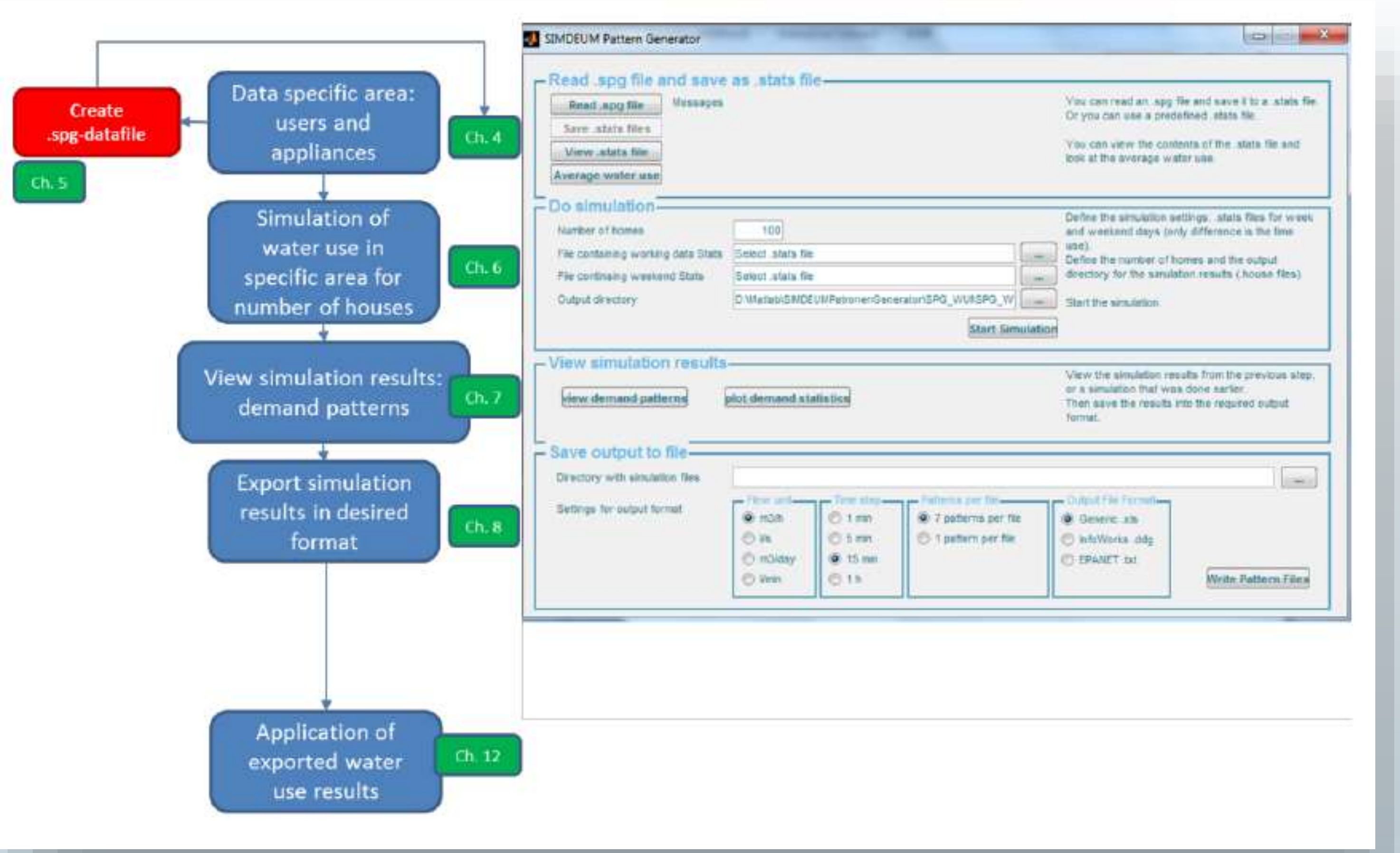
Mirjam Blokker

My message

1. Understanding demands = key in the water cycle
2. In order to understand demand a (conceptual) model is required
3. Your goal determines the required temporal and spatial scale
4. Possible to aggregate from small scale to larger, but not the other way around
5. Dreaming of the ideal hydraulic / demand model

How SIMDEUM works

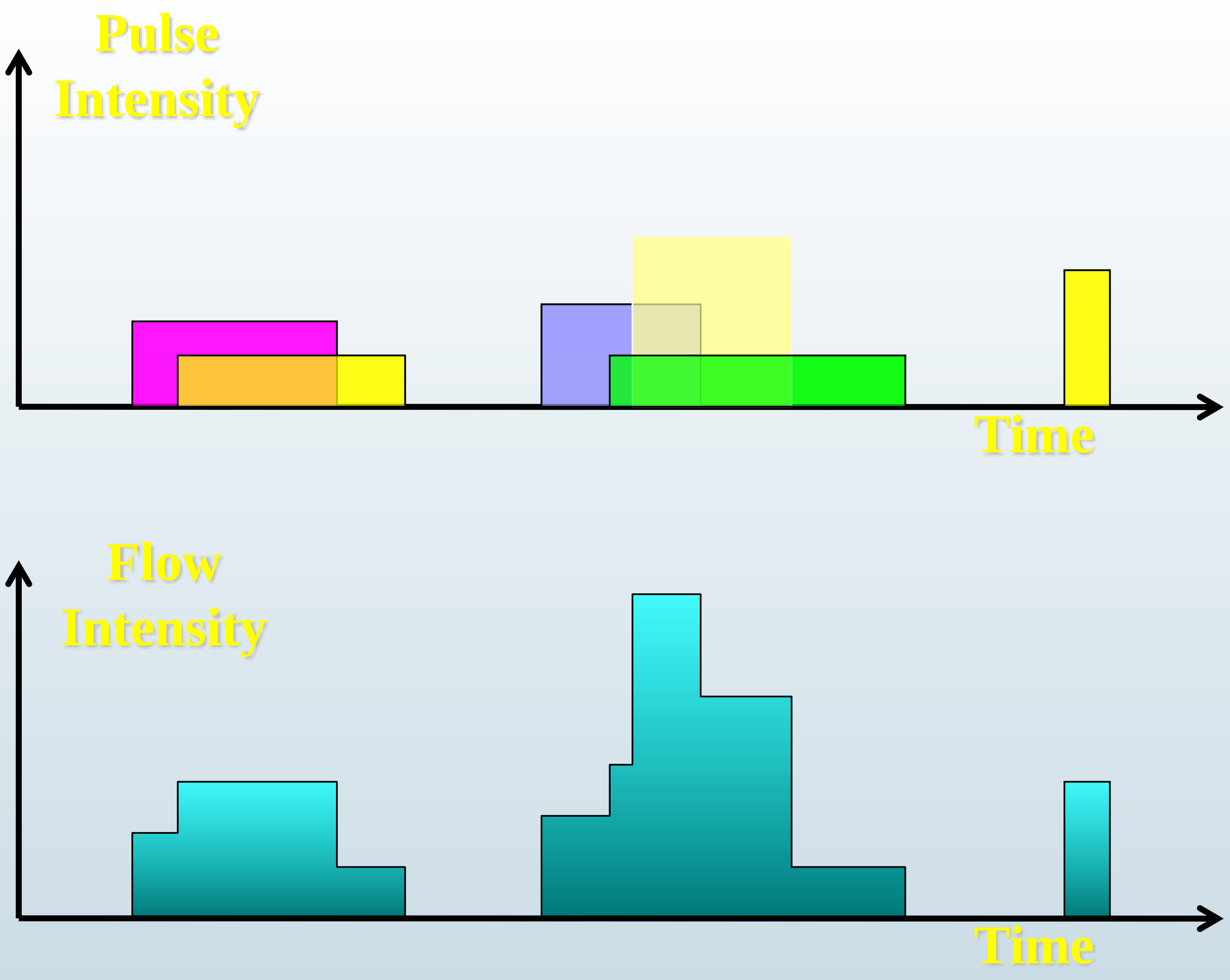




Basic principle of stochastic demand model

$$B(I,D,\tau) = \begin{cases} I & \tau < T < \tau + D \\ 0 & elsewhere \end{cases}$$

$$Q = \sum B(I,D,\tau)$$



Source: Buchberger, 2007

SIMDEUM: parameters follow from surveys and information on appliances

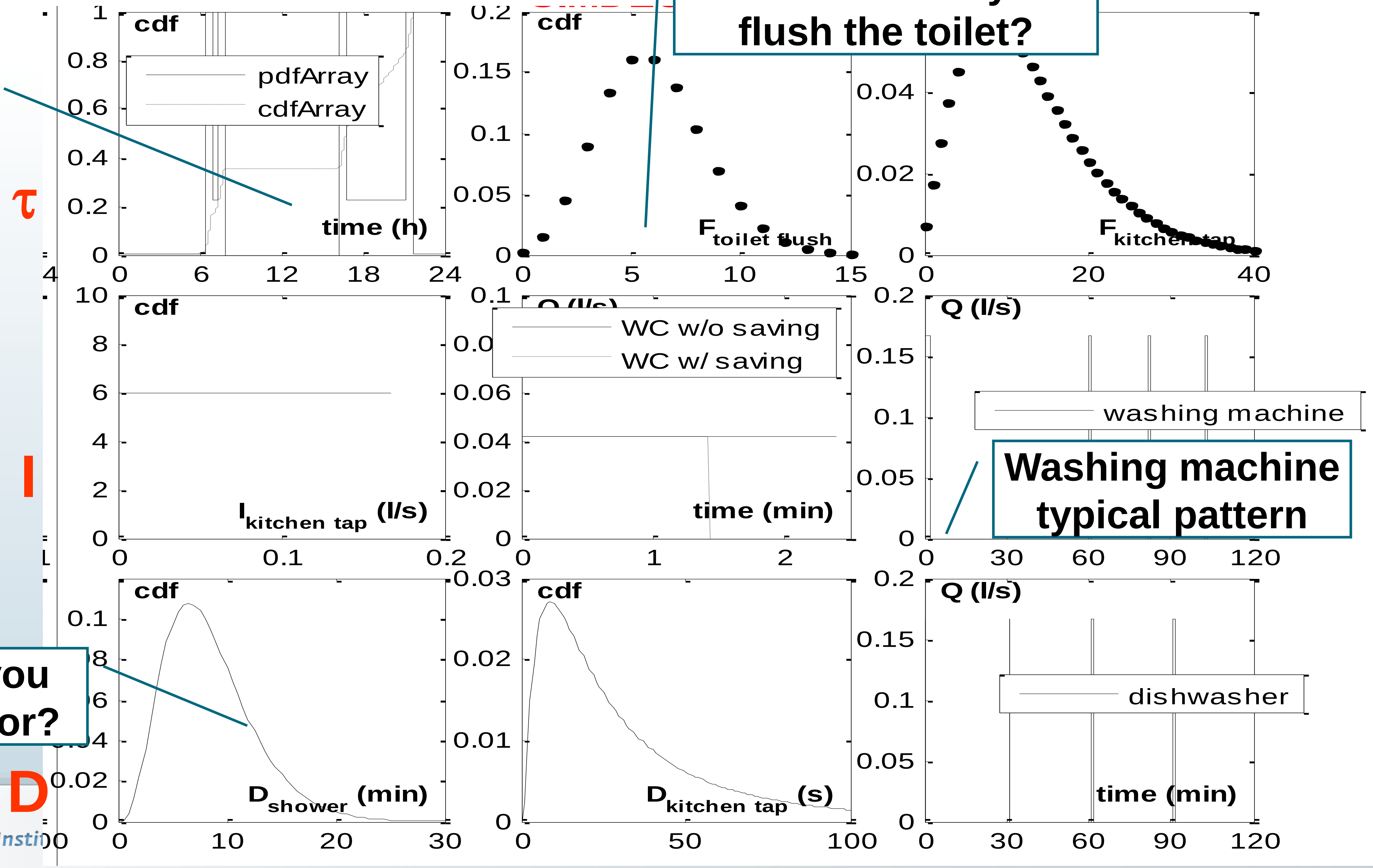
When did you get up, leave the house, go to bed?

No flow measurements

How long did you take a shower for?

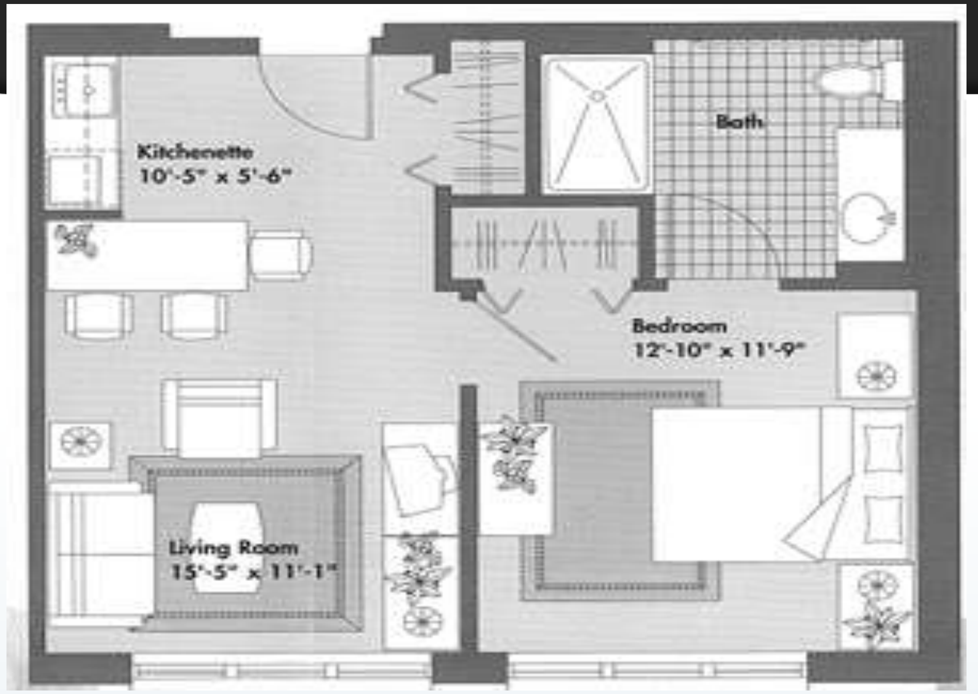
How often did you flush the toilet?

Washing machine typical pattern



SIMDEUM steps (1)

Apartment building – users and installation

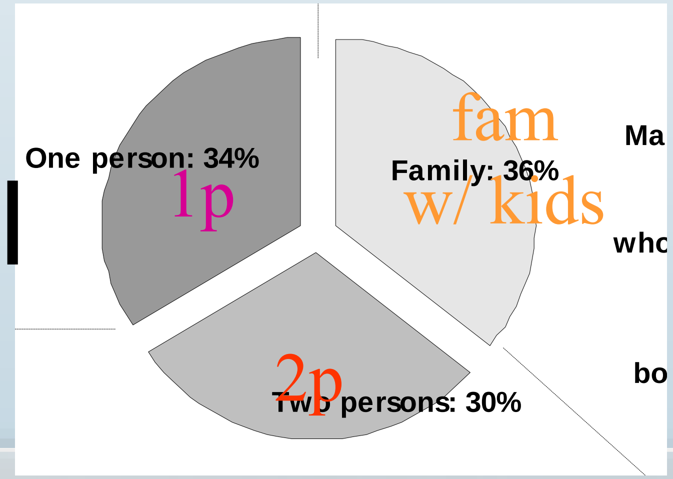


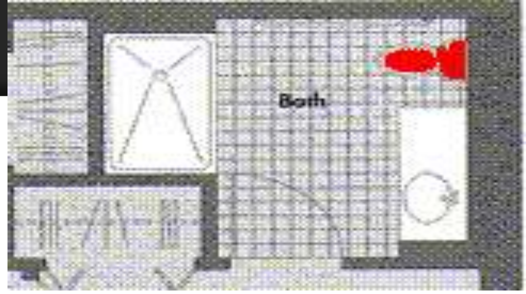
5 people: dad, mum, 3 children

Bathroom: bath, shower, toilet, sink

Kitchen: sink, dishwasher, washing machine

Average 2.3 people/home

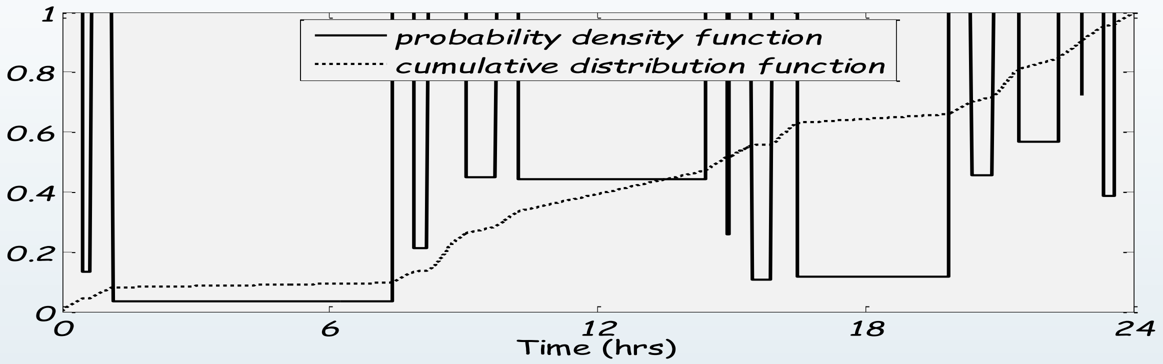




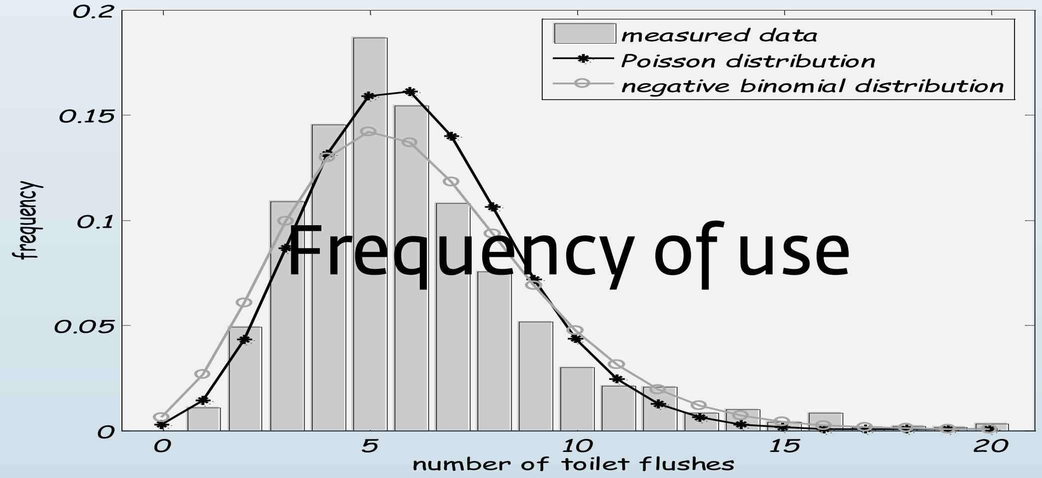
SIMDEUM steps (2)

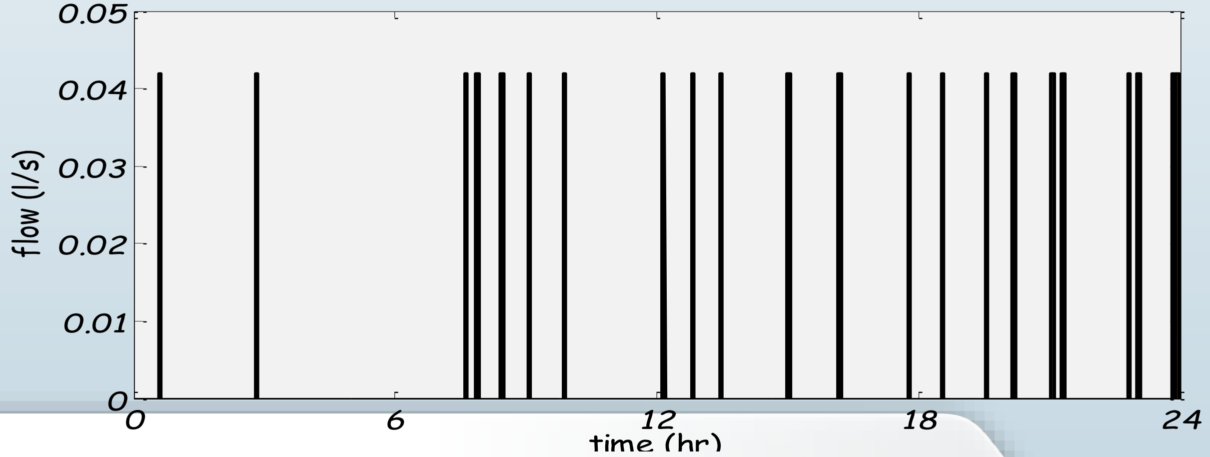
Toilet flush demand

5 users, probability of use



Generate diurnal demand

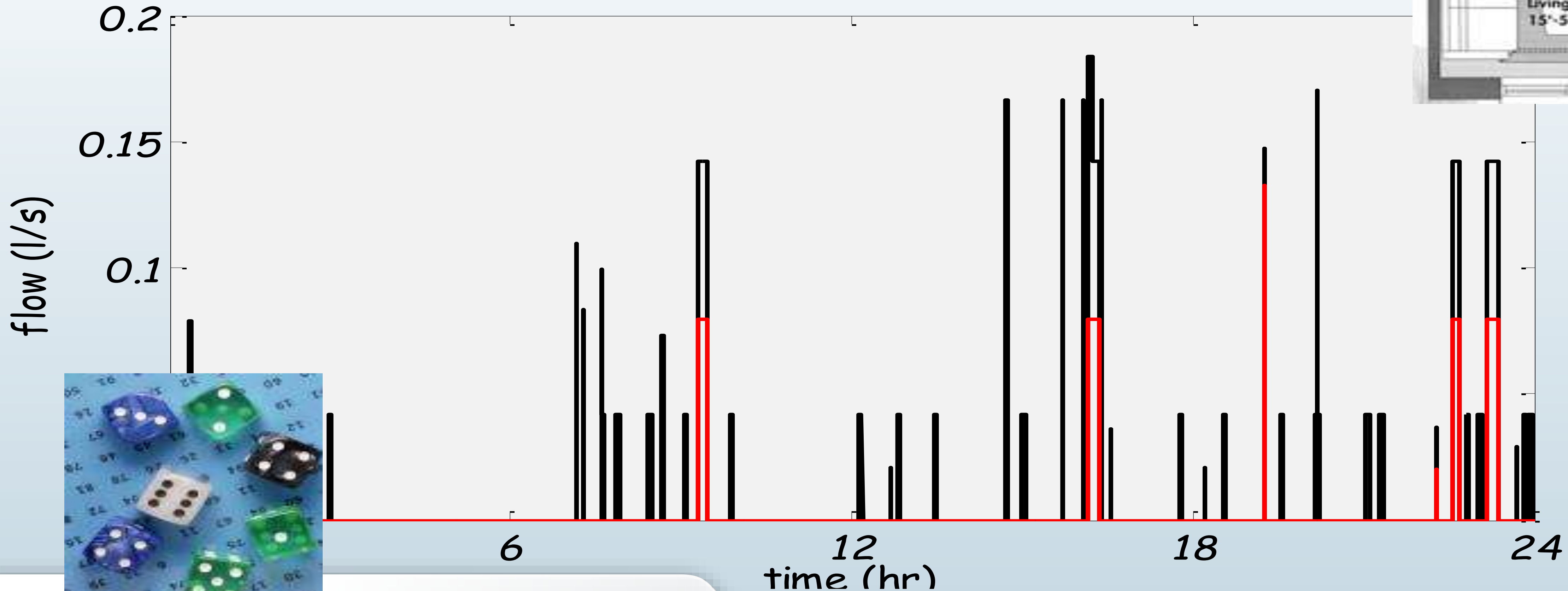


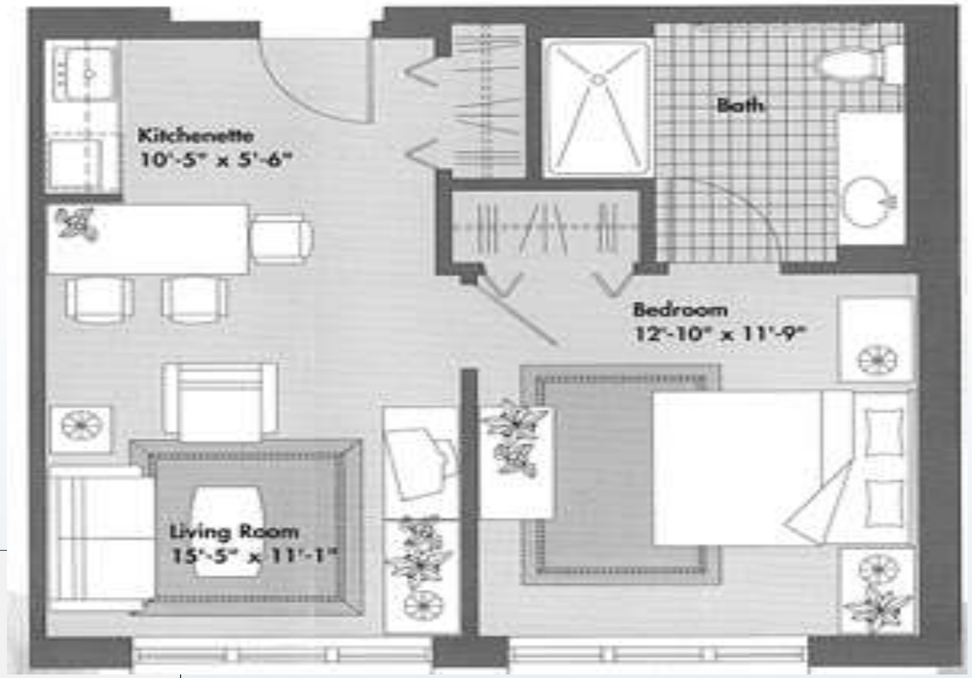


SIMDEUM steps (3)

Total demand for one house

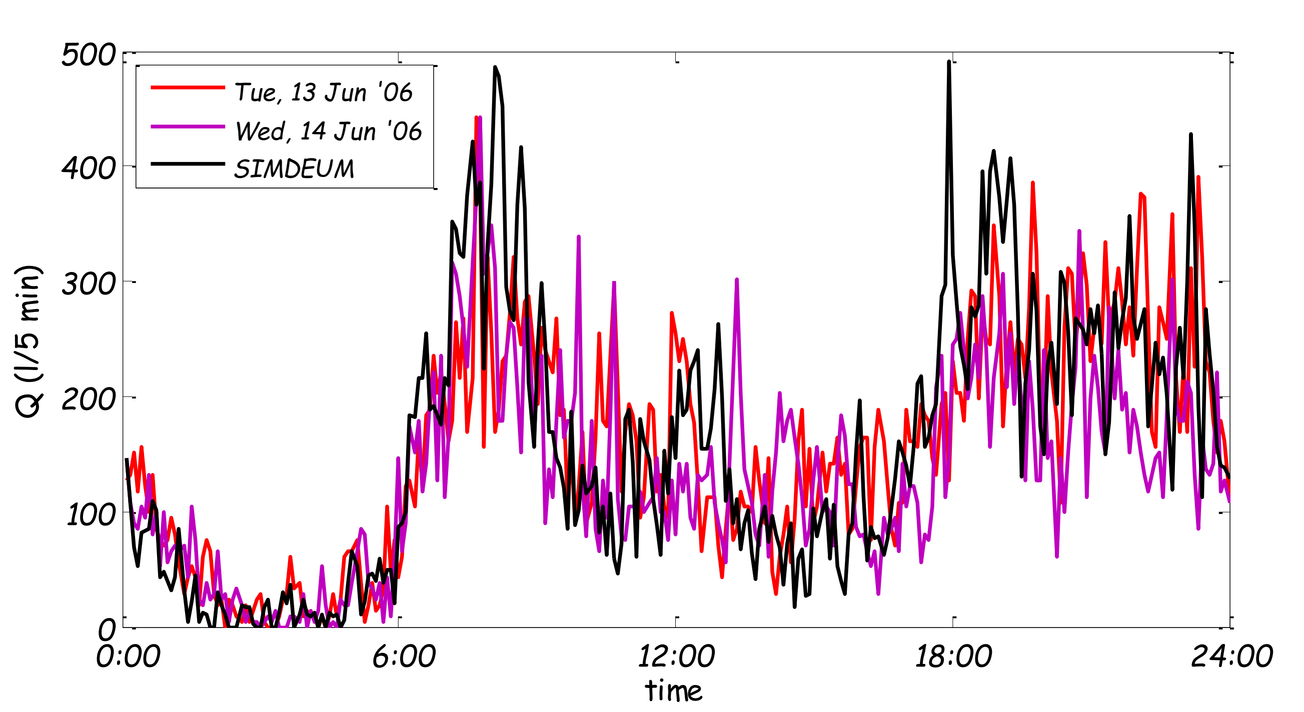
Toilet, shower, washing machine, etc

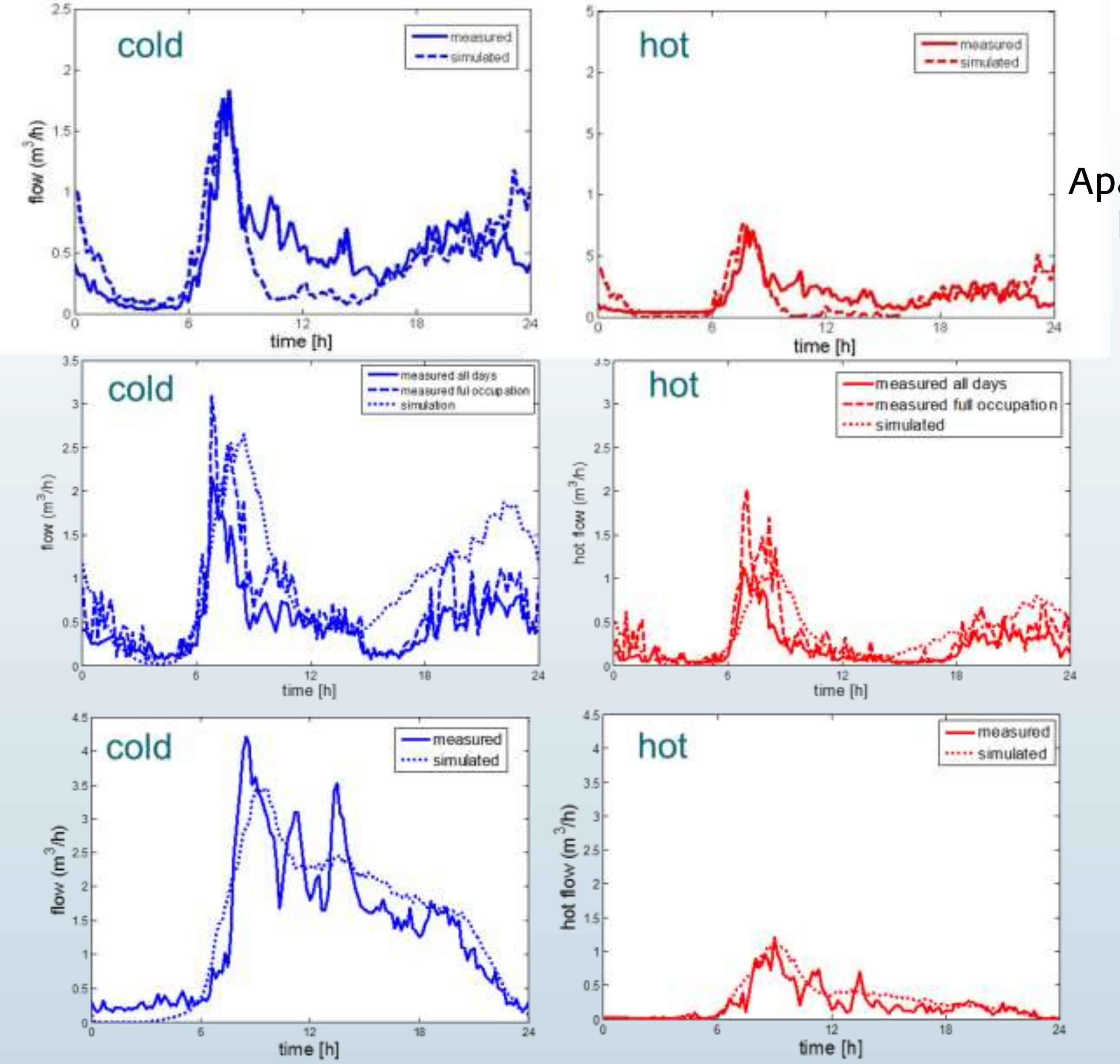




Validation of SIMDEUM (1)

Demand patterns





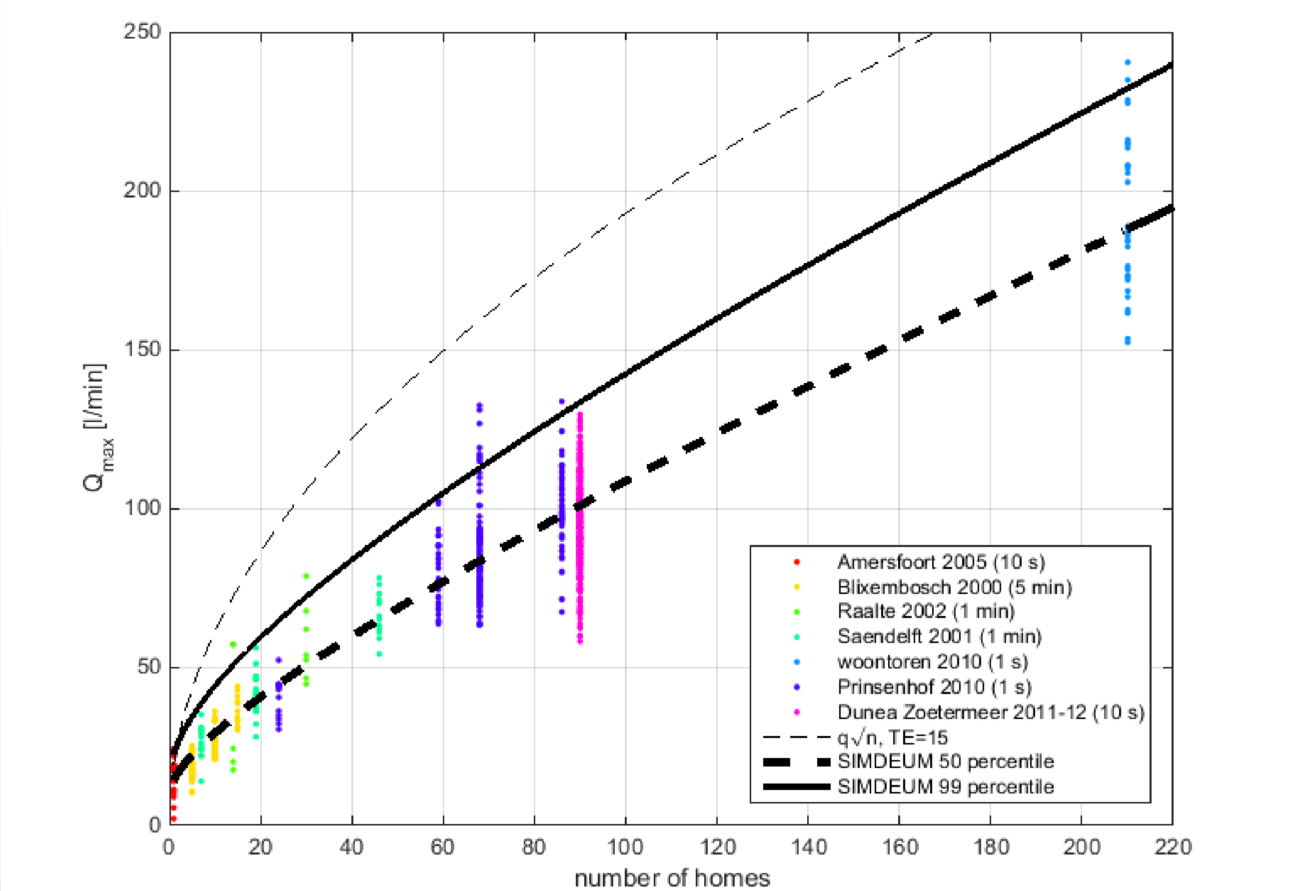
Apartment building

Hotel

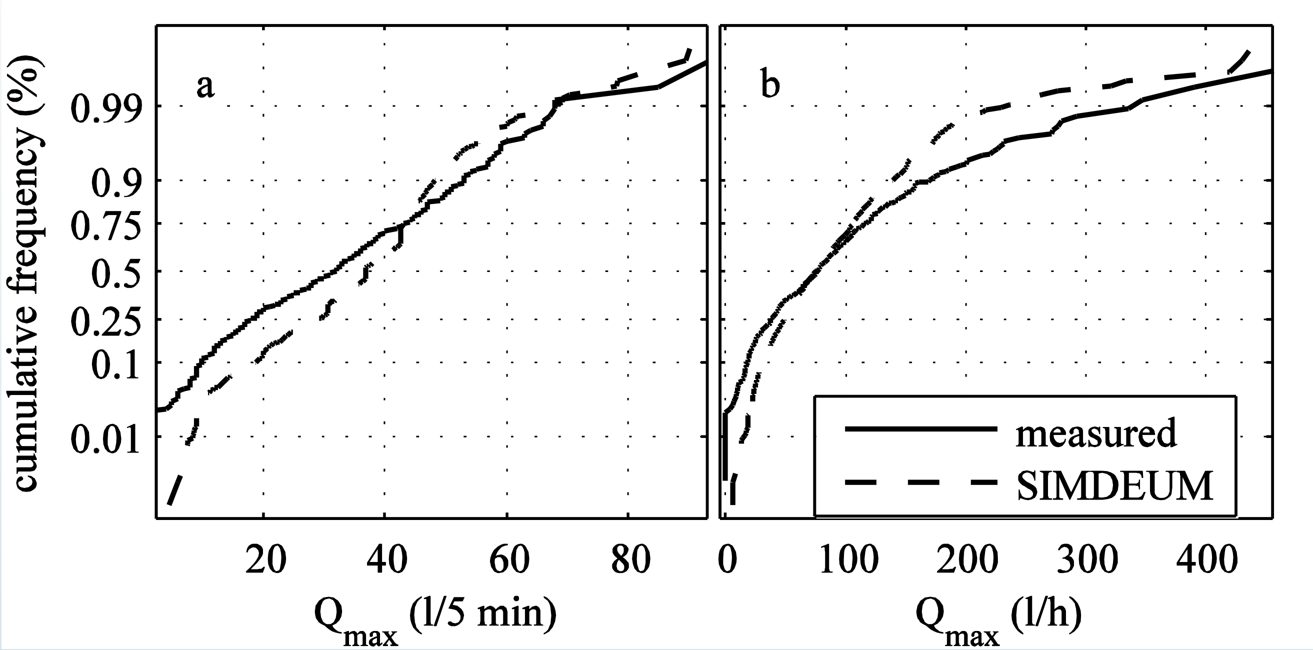
Nursing home

Validation of SIMDEUM (2)

Maximum flow velocities

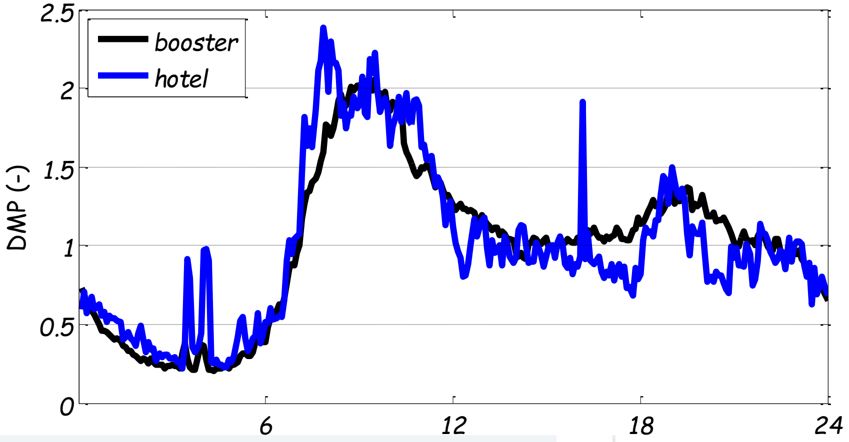


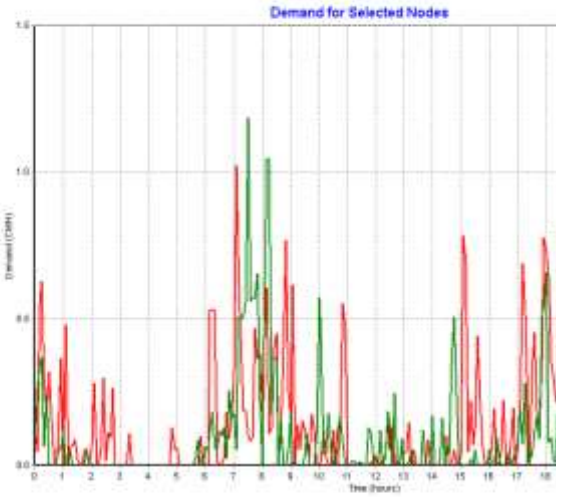
NOTE THAT Q MEASUREMENTS MAY INCLUDE EXTRA FLOW FOR WATER QUALITY SENSOR MEASUREMENTS

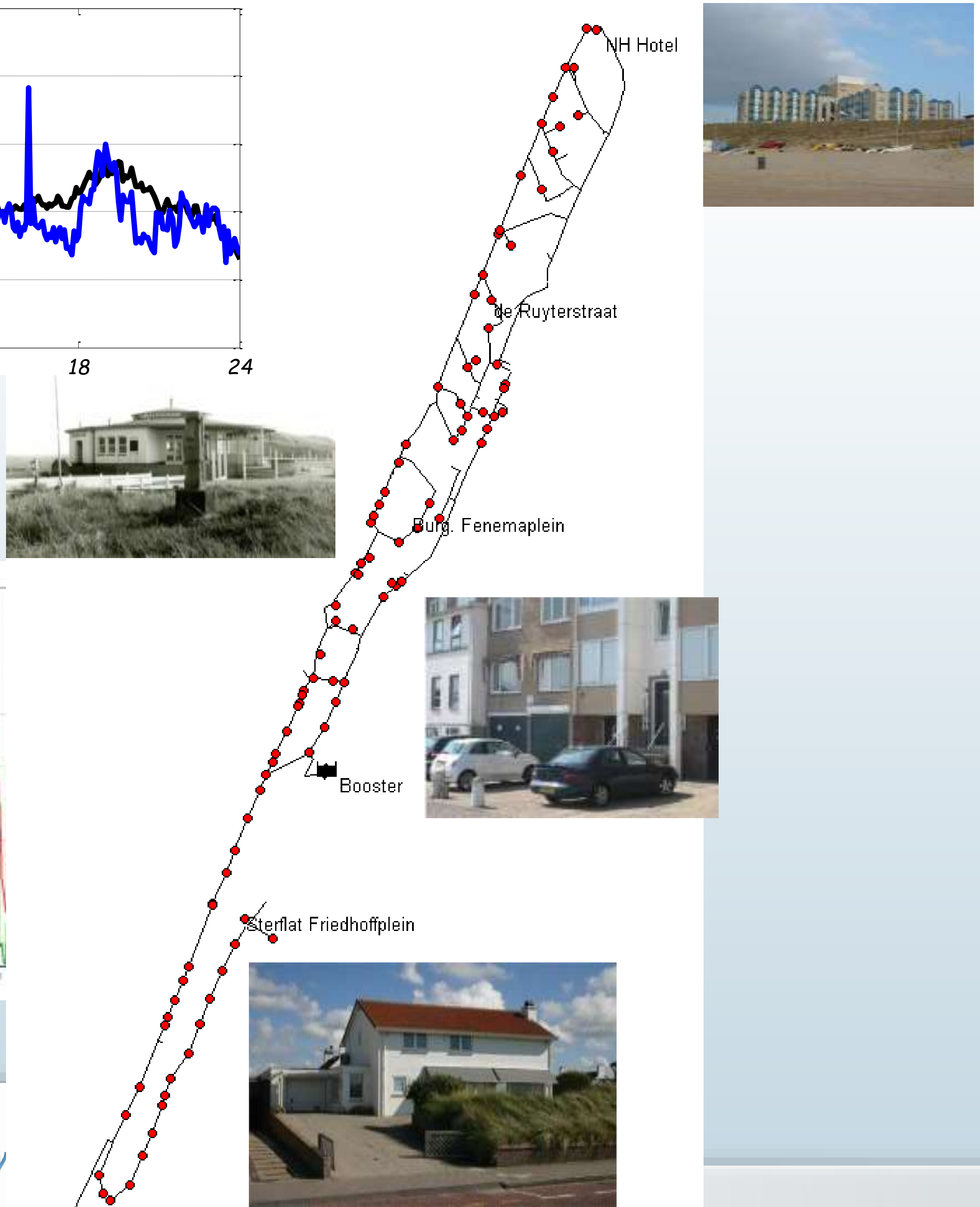


SINGLE HOME, 300 MEASURED PATTERNS, 100 SIMULATED PATTERNS

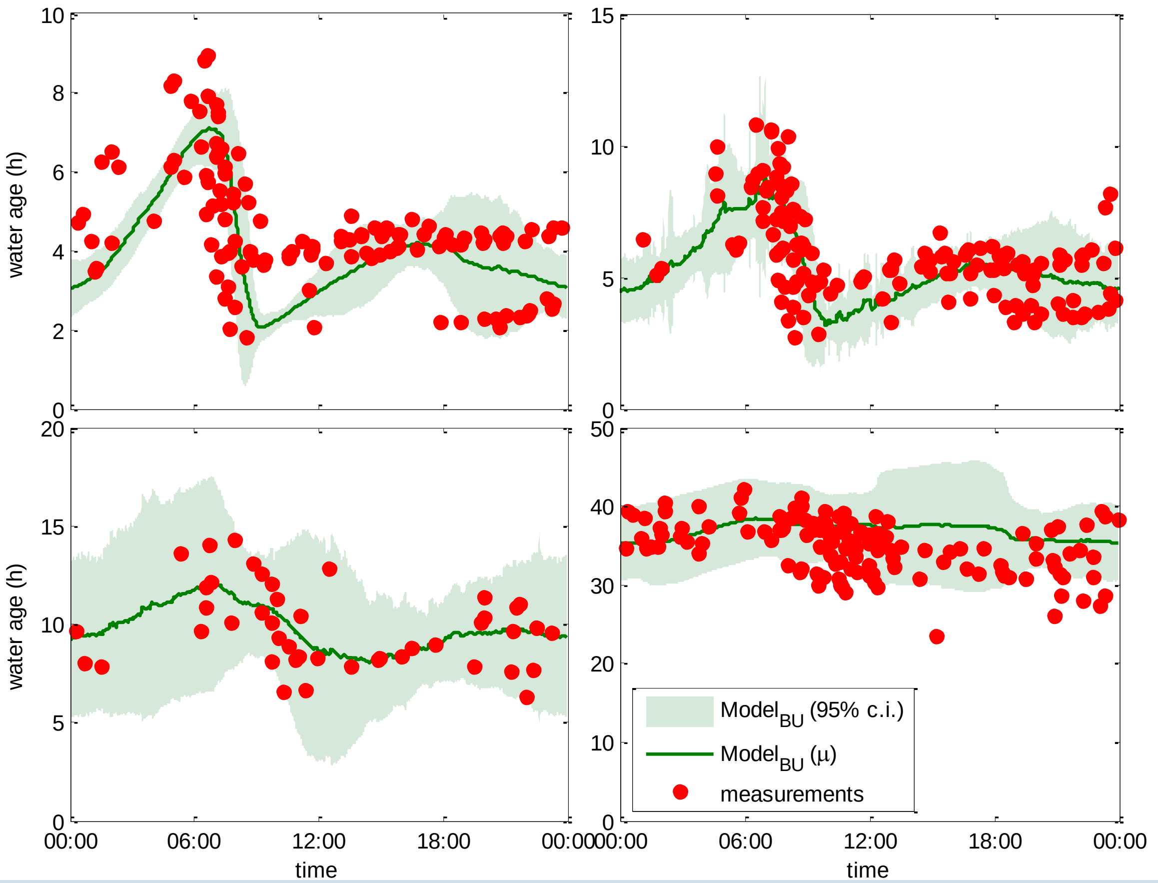
Validation of SIMDEUM (3)







Residence time



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Understanding demands = key + model required

Examples

Understanding demands = key + model required

Examples

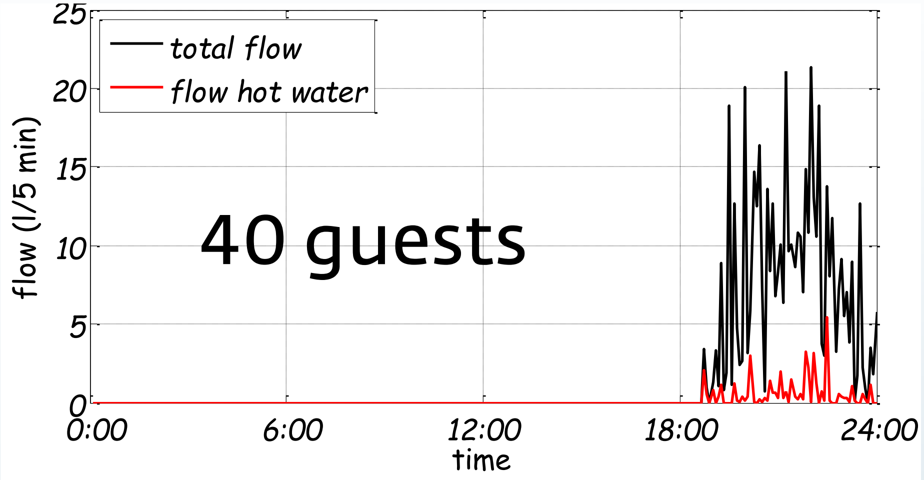
How to design a drinking water installation?

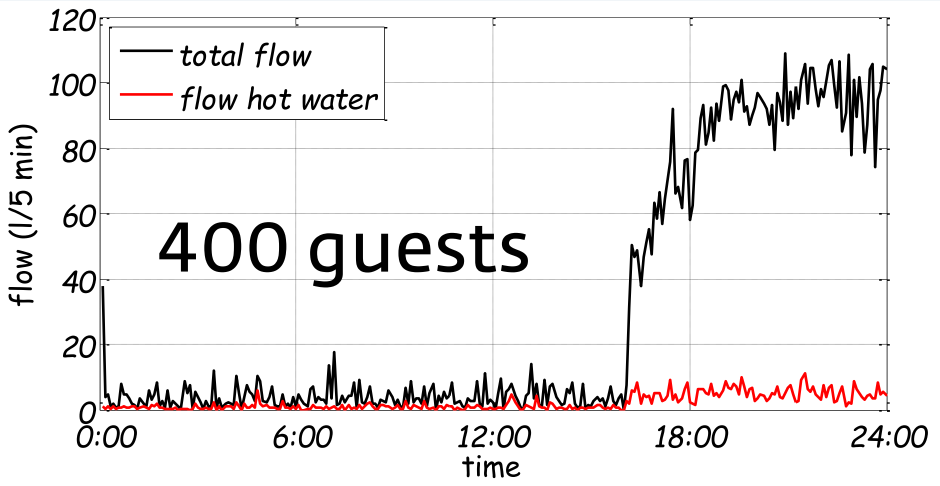
Cinema

Counting "tap units"

		#	TU	freq
Ladies				
	wc	6	6* 0.25	2
	Tap	6	6* 1	4.5
Gents				
	wc	2	2* 0.25	0.5
	urinal	8	8* 4	1.5
	tap	6	6* 1	4.5

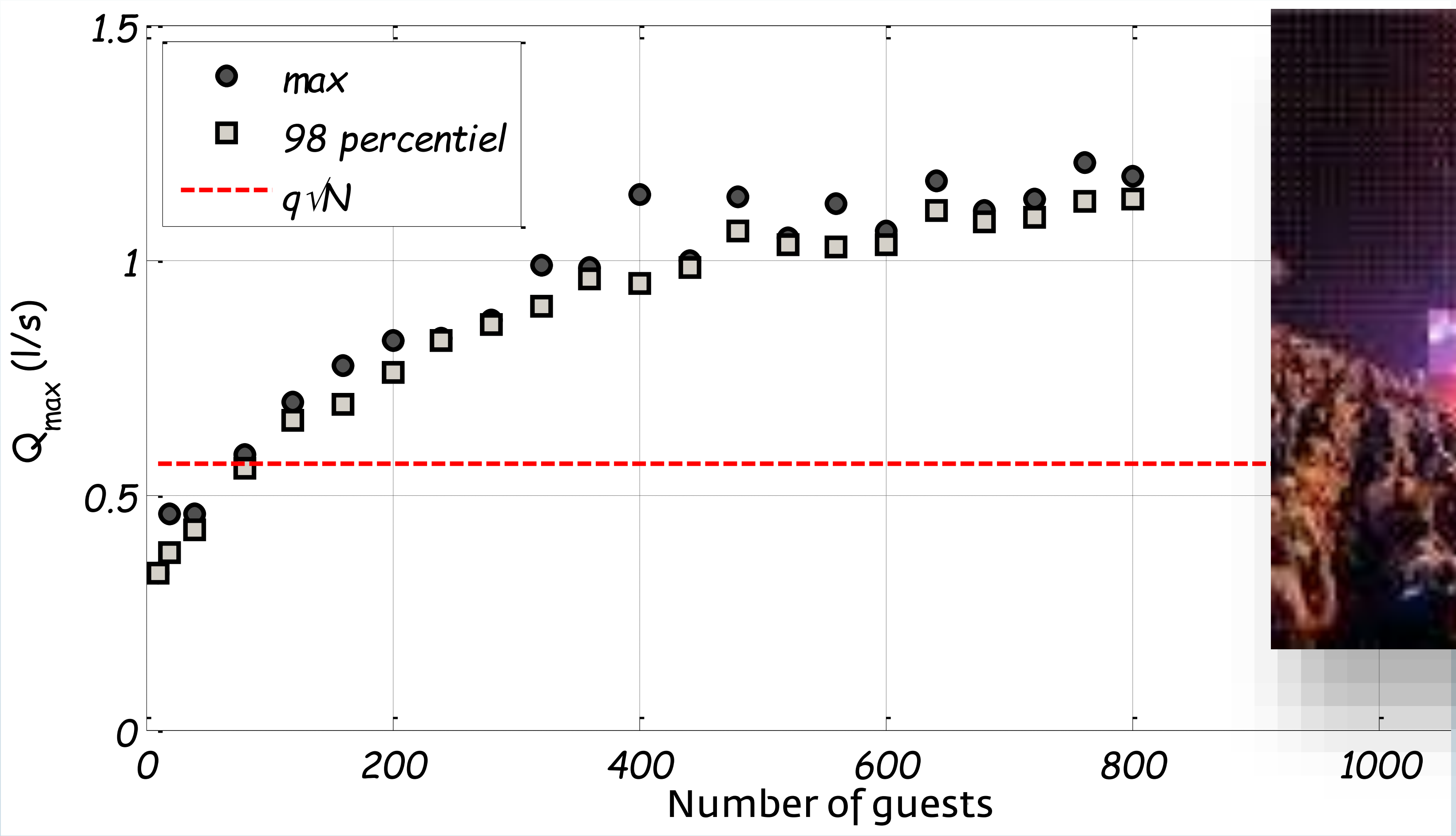
Sum is 46 ➔ Q_{max} = 0.56 l/s



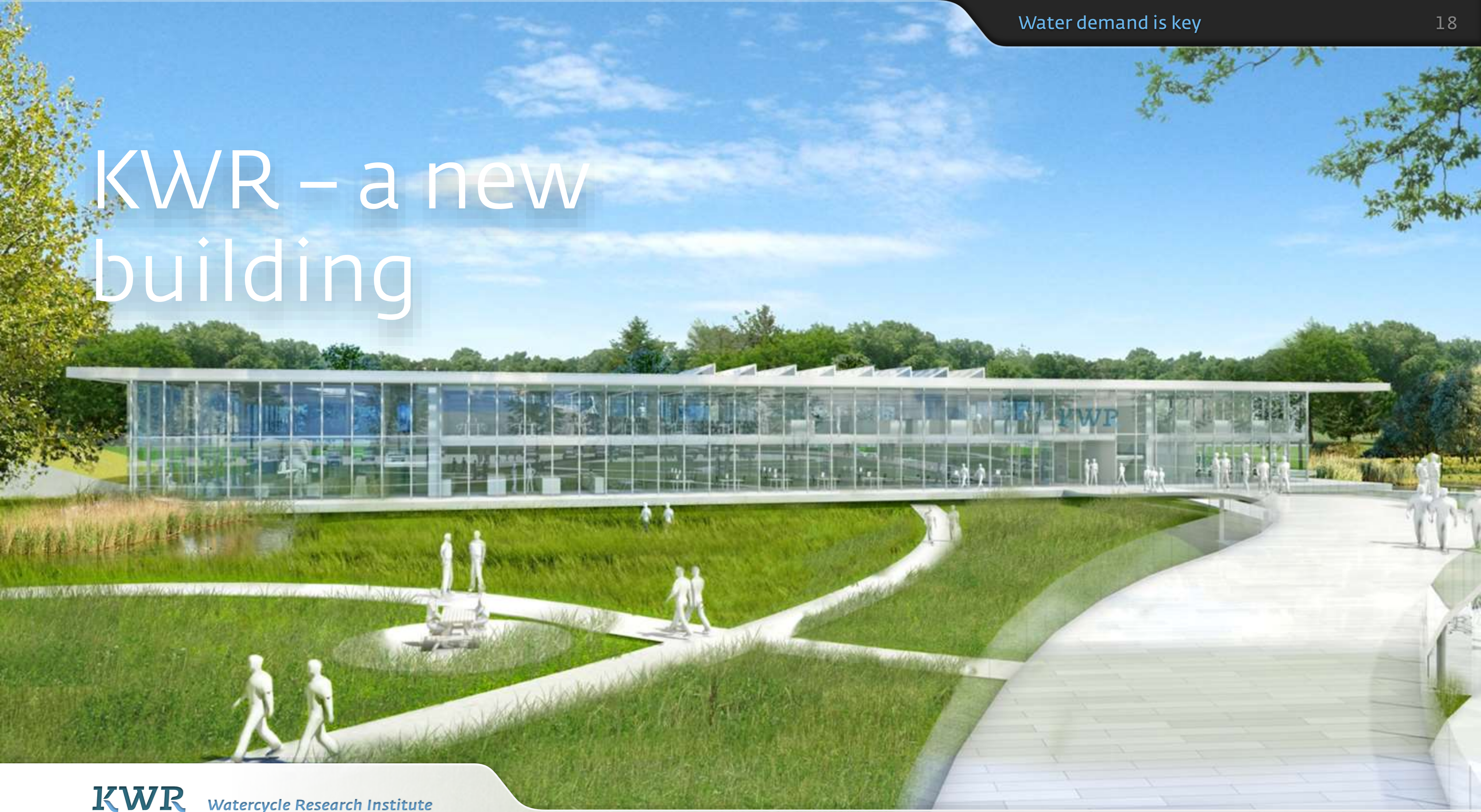


Cinema or concert hall

Take users into account . . .



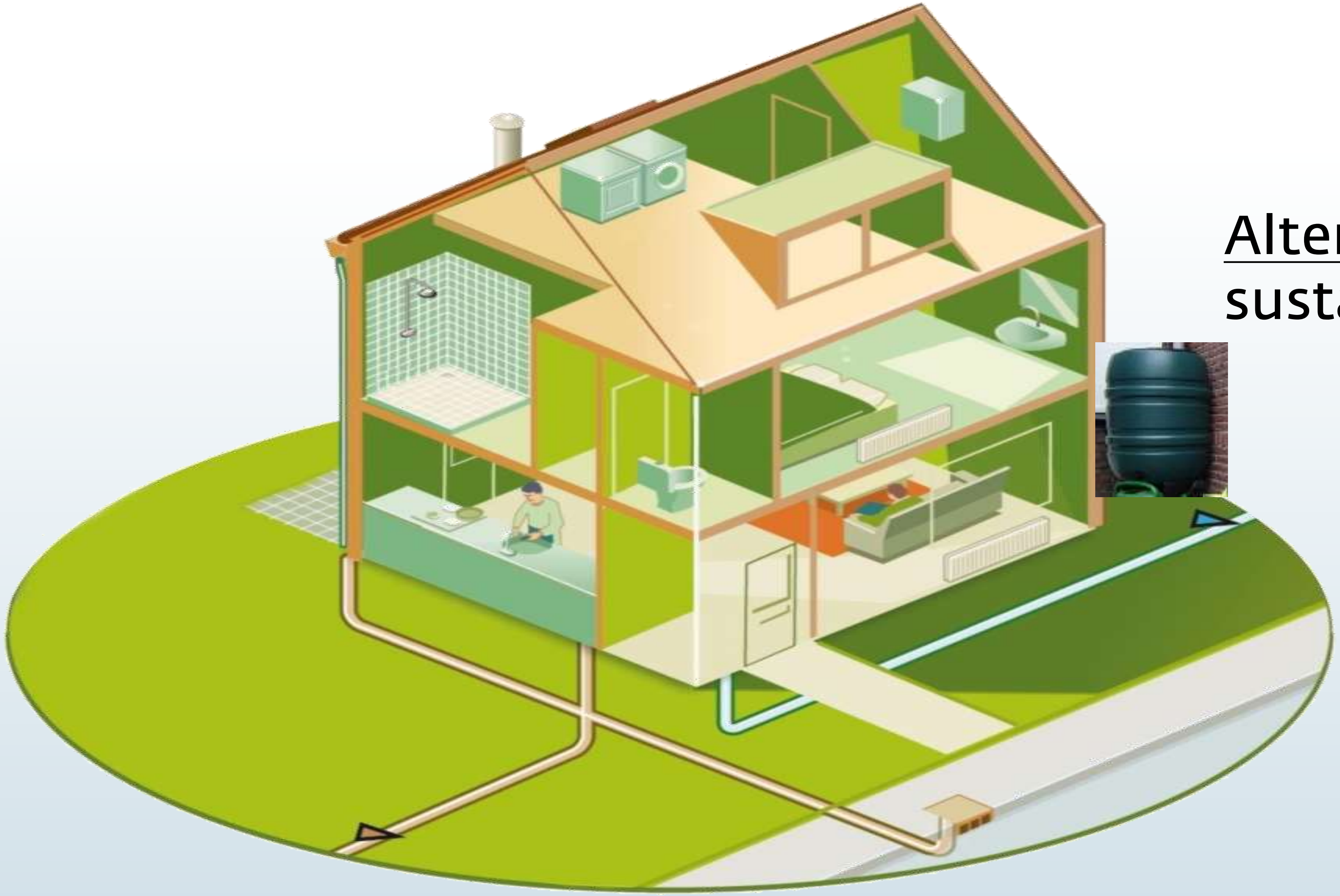
KWR – a new building



Understanding demands = key + model required

Examples

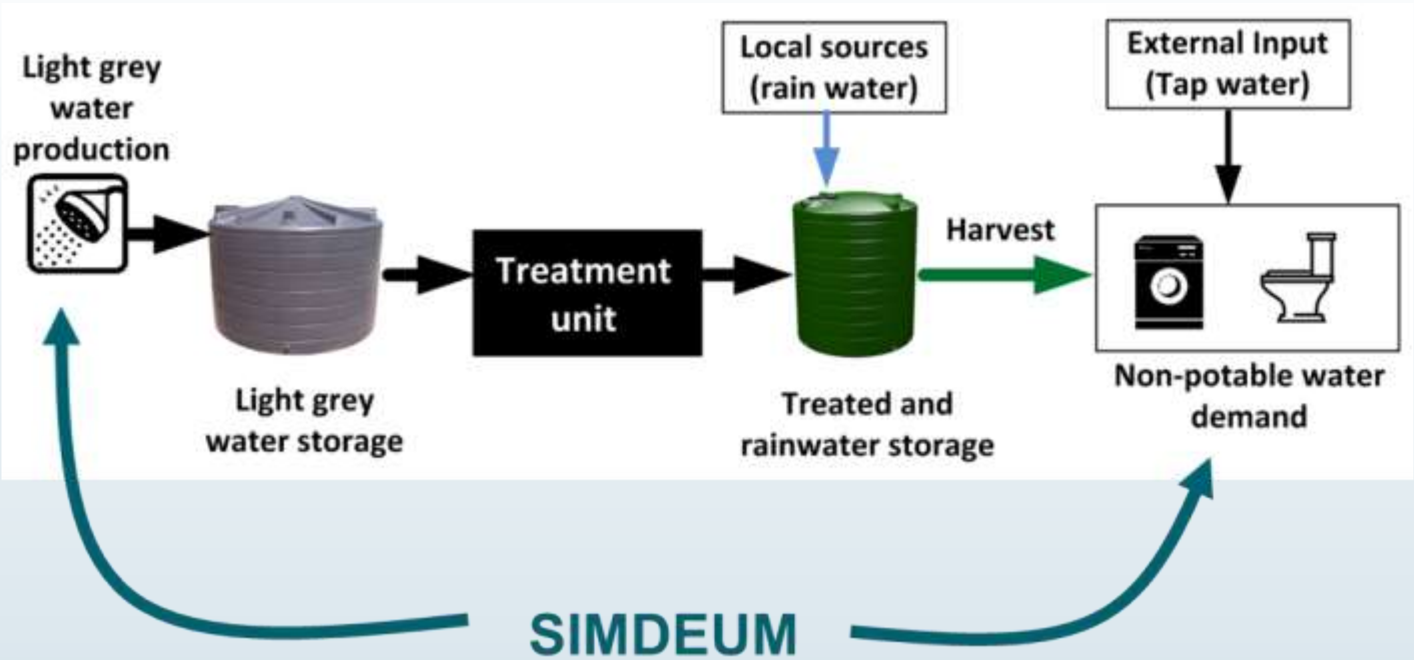
How to design a residential drinking water installation?



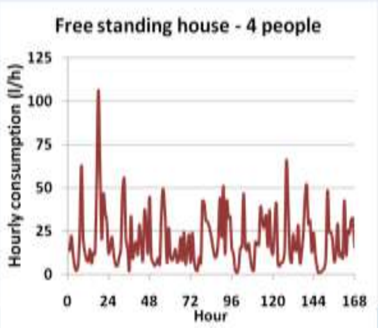
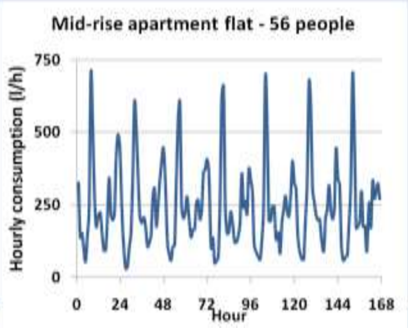
Alternative sources
sustainable use

Recycling light grey water and harvesting rainwater

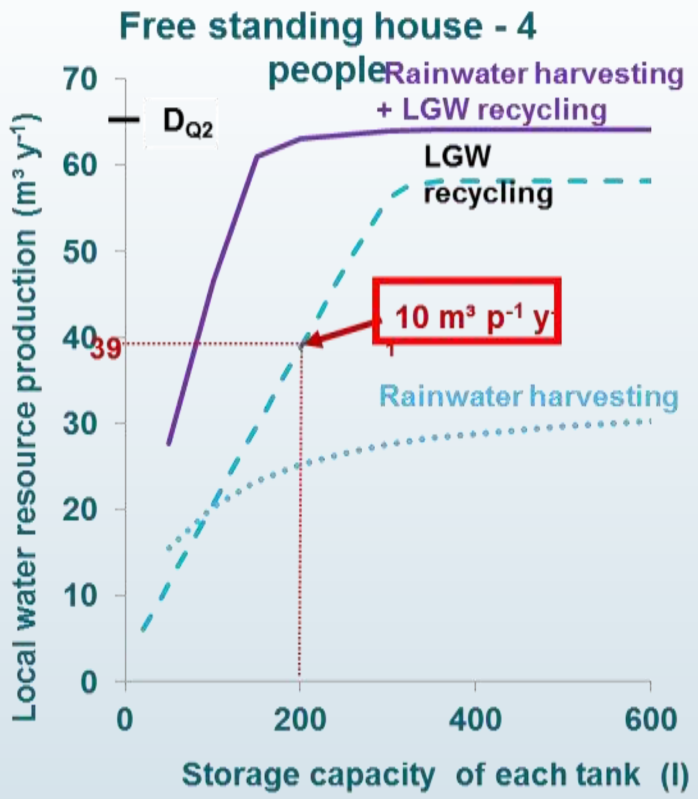
Balancing grey water supply and demand

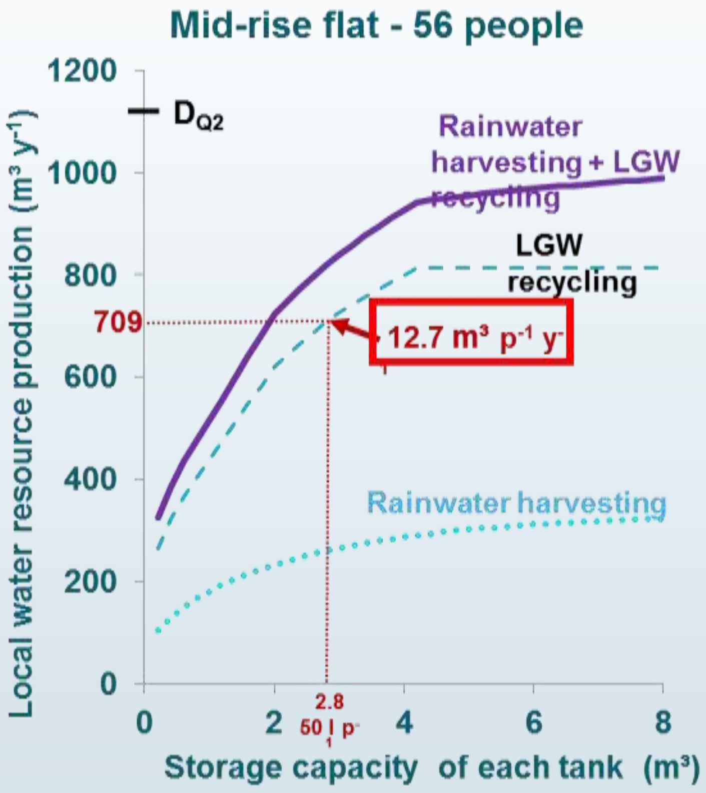


Drinking water demand model

Building type	Free standing house 	Mid-rise apartment flat 
Occupancy	4 people (1 family)	56 people (28 apartments x 2 people)
Roof area (m²)	60	640
# of toilets	2 (1 in each floor)	28 (1 per apartment)
# of laundry machines	1 (in 1st floor)	28 (1 per apartment)
# of showers/bathtubs	1 (in 2nd floor)	28 showers (1 per apartment) – No bath
Grey and rain water system	Single house collection	Shared collection
Week demand pattern (hourly time step)		

Balancing grey water supply and demand

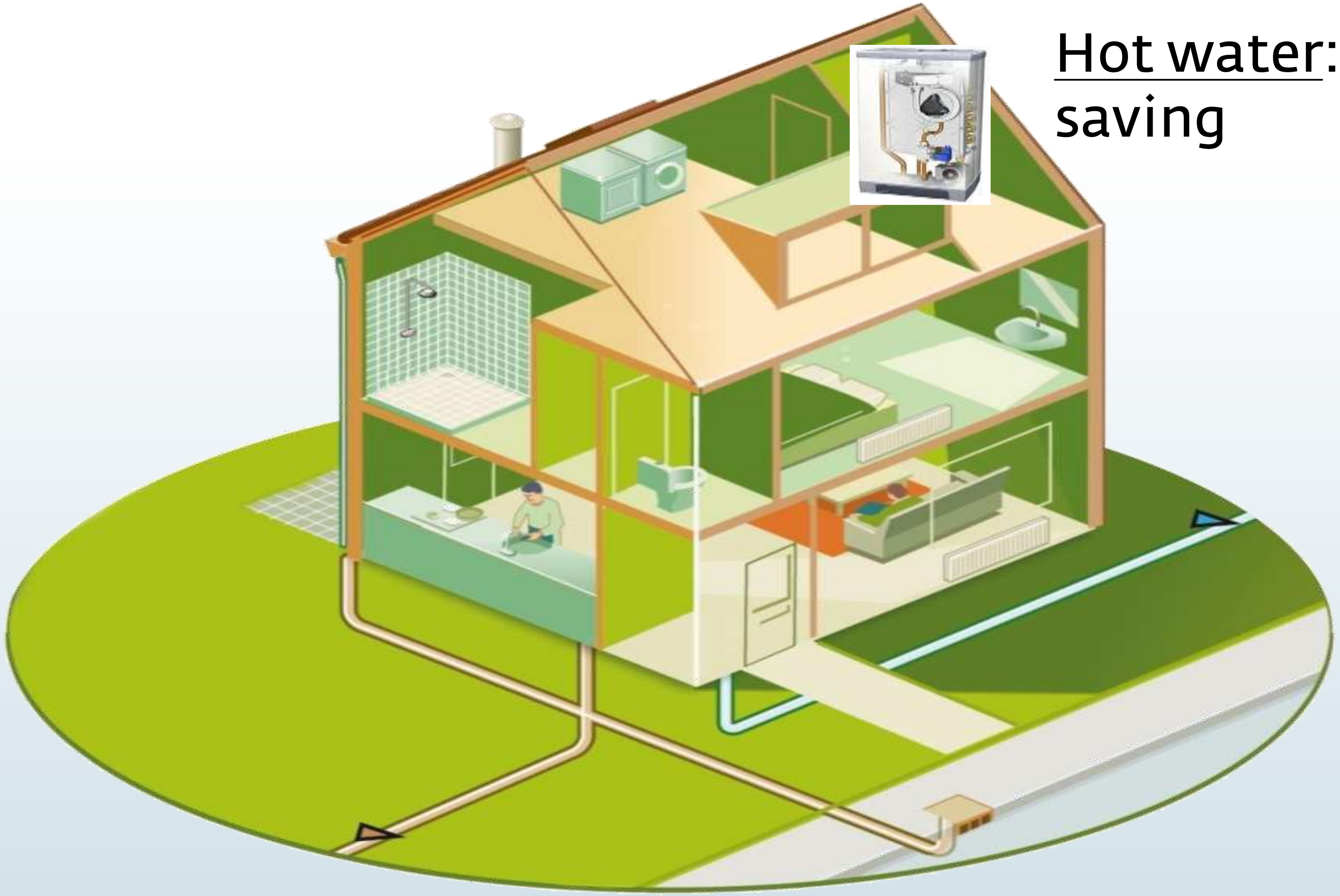




Non-potable demand (D_{Q2}) = 65 $m^3\ y^{-1}$ = 16 $m^3\ y^{-1}\ p^{-1}$
Potential recycling = 85 $m^3\ y^{-1}$ = 21 $m^3\ y^{-1}\ p^{-1}$
Potential rainwater harvesting = 48 $m^3\ y^{-1}$ = 12 $m^3\ y^{-1}\ p^{-1}$
Treatment rate = 160 $l\ d^{-1}$ = 40 $l\ d^{-1}\ p^{-1}$

Optimisation for choice of storage capacity shows:

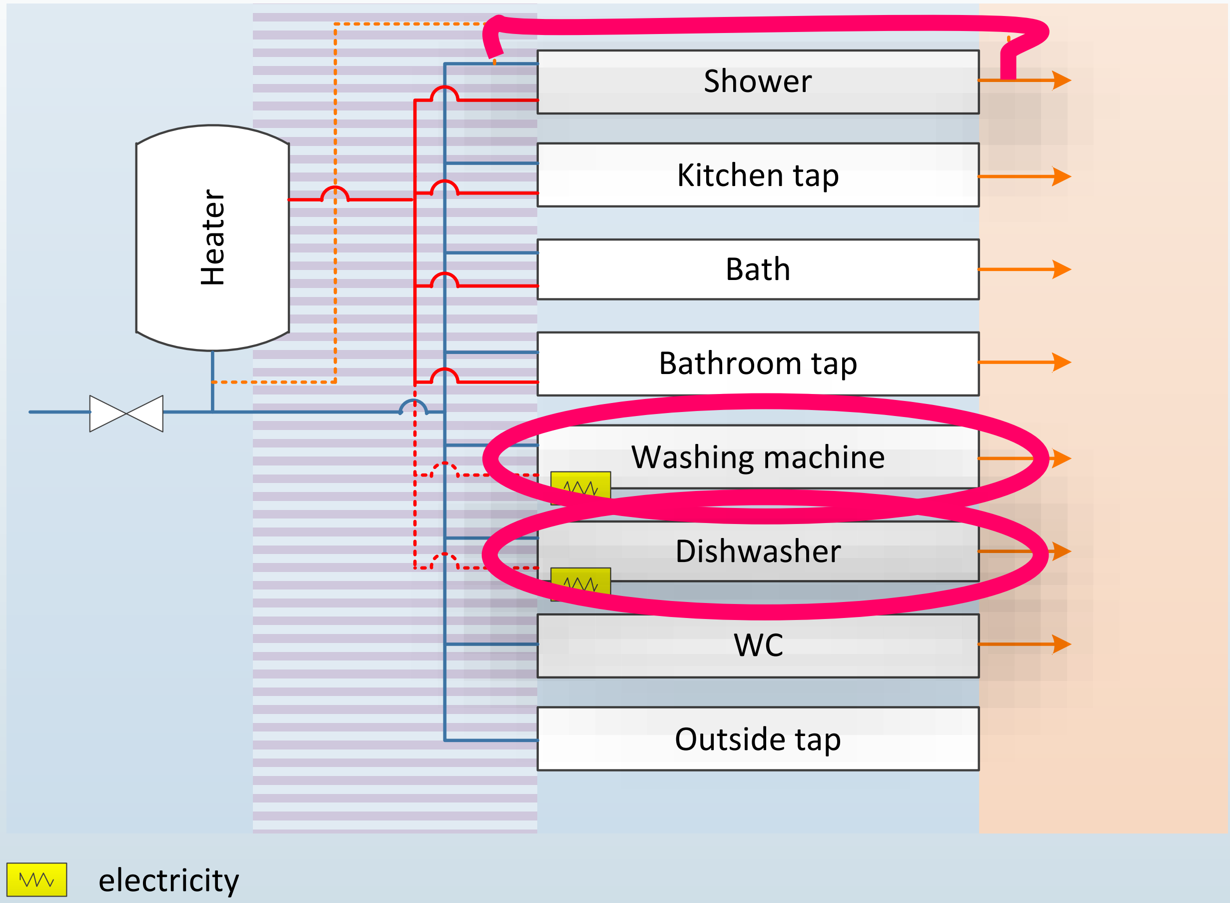
1. **LGW recycling** is more beneficial than **rainwater harvesting**, for the same storage capacity
2. **Combine LGW and rainwater**: maximum yield at smaller storage capacity

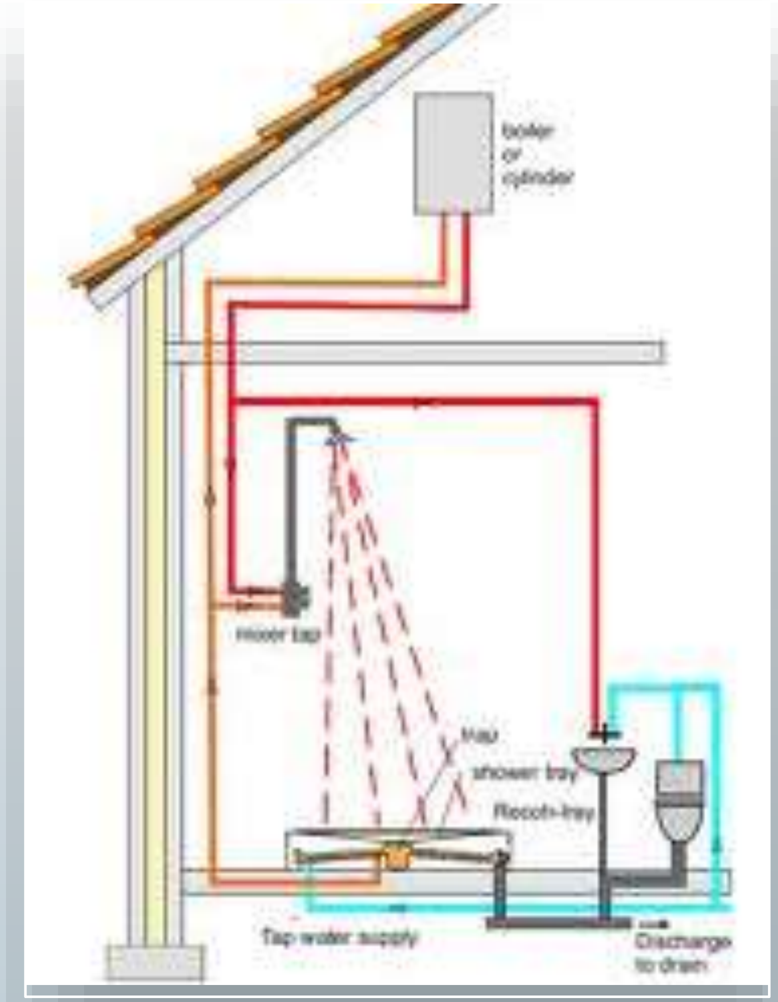


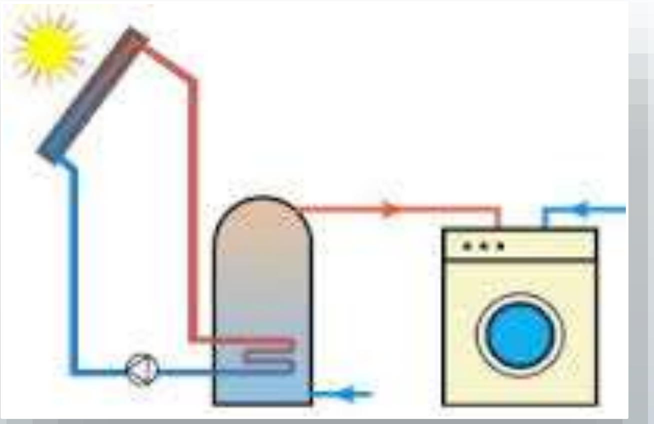
Hot water: energy saving

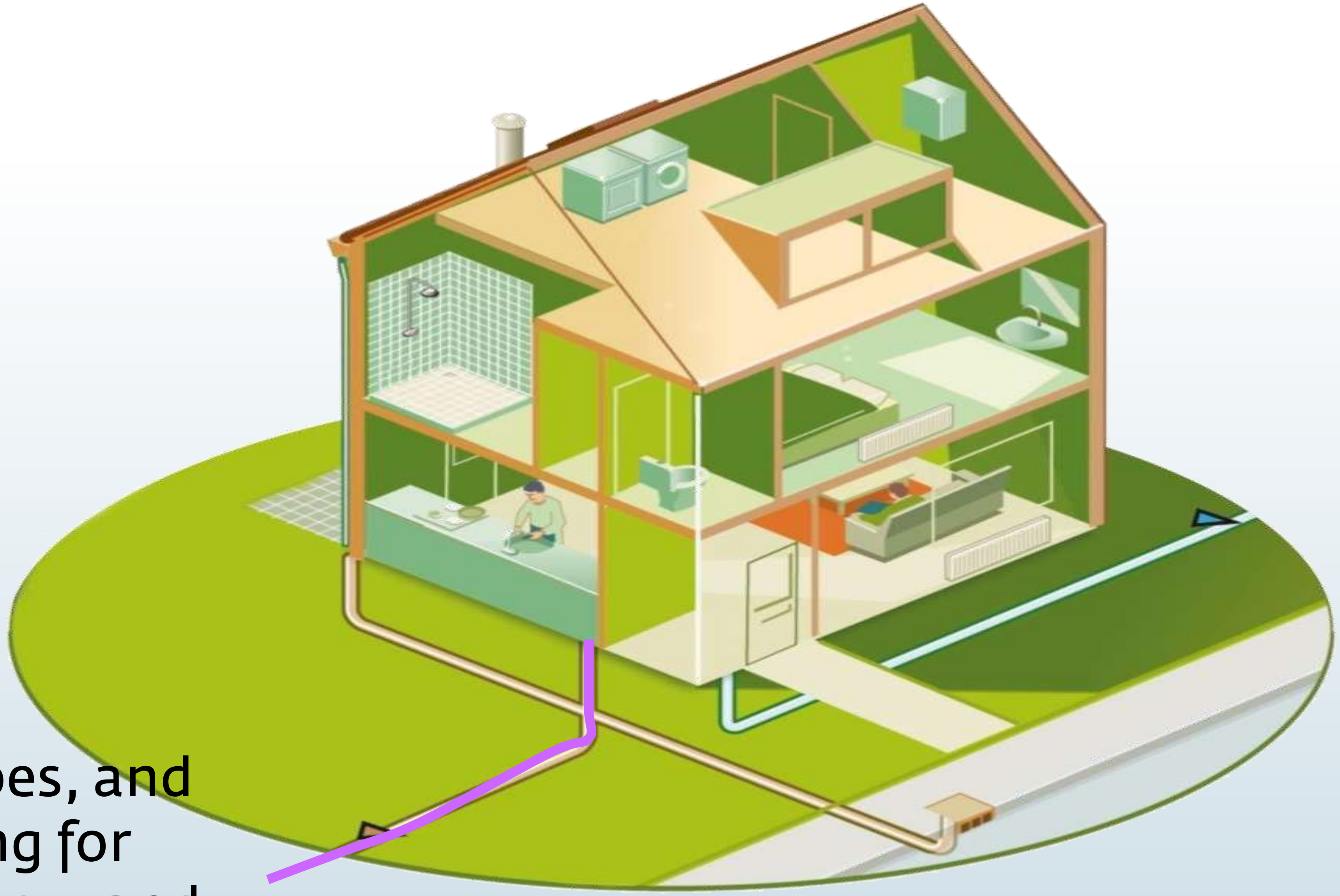
Water & energy: heating water for washing

Clothes washing, dishes, showering





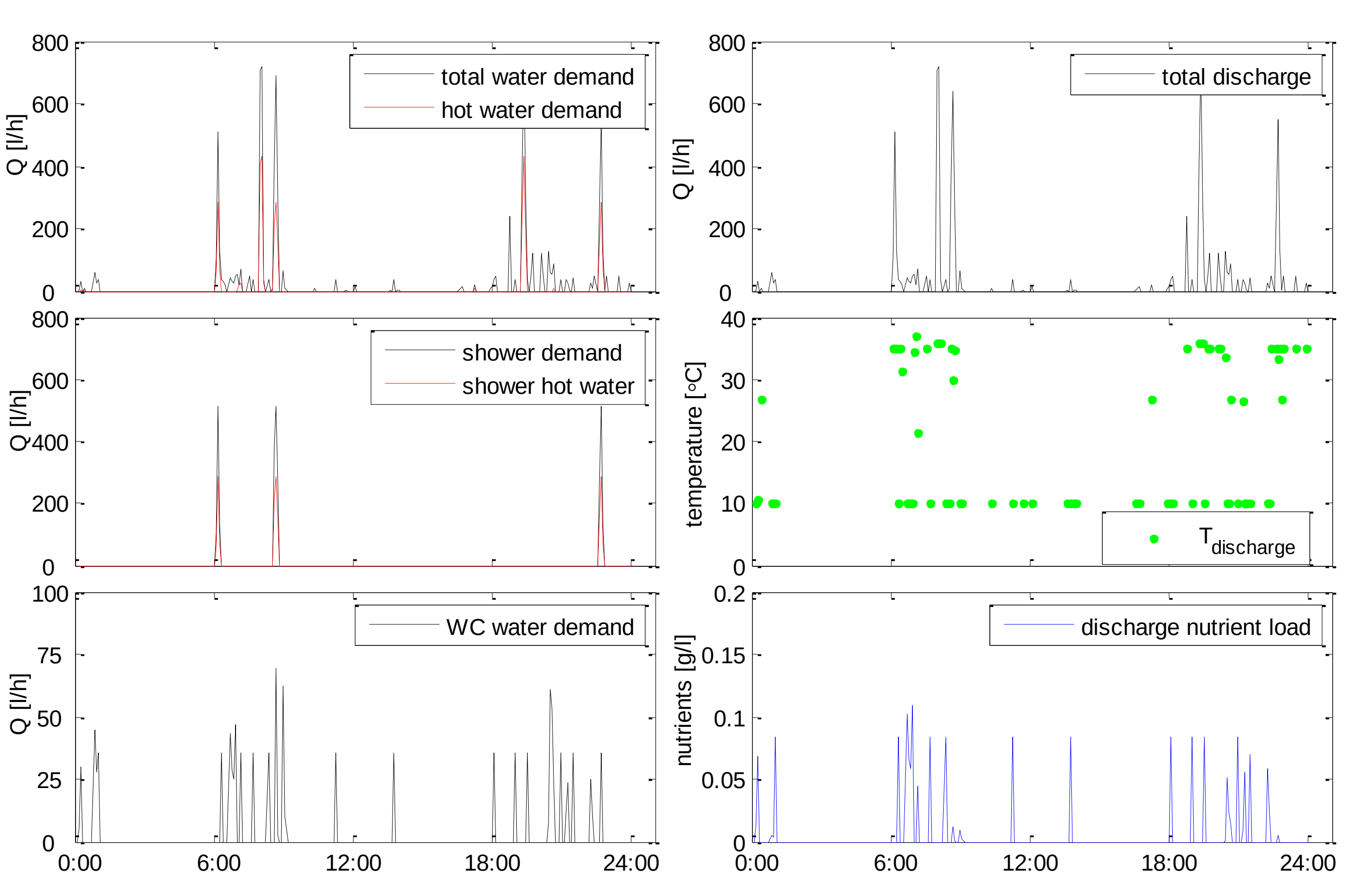


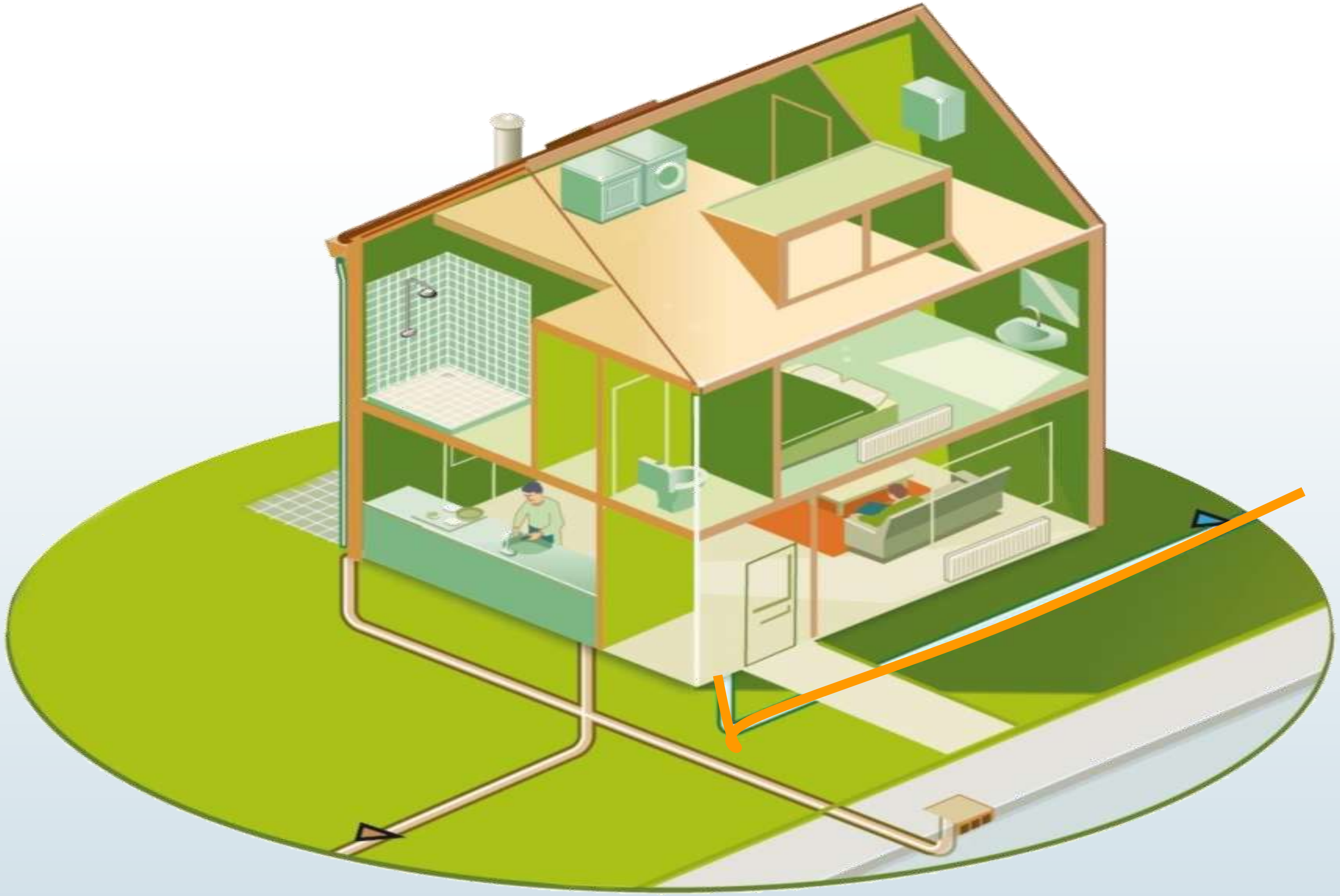


discharge:
Sizing of pipes, and sewer mining for thermal energy and nutrients

Discharge patterns: temperature and nutrien

The water that is discharged contains nutrients and thermal energy that may be recovered; here a hydraulic and water quality model helps to identify the best strategy.





Drinking water supply:
Sizing of pipes, and fit for purpose water quality

Understanding demands = key + model required

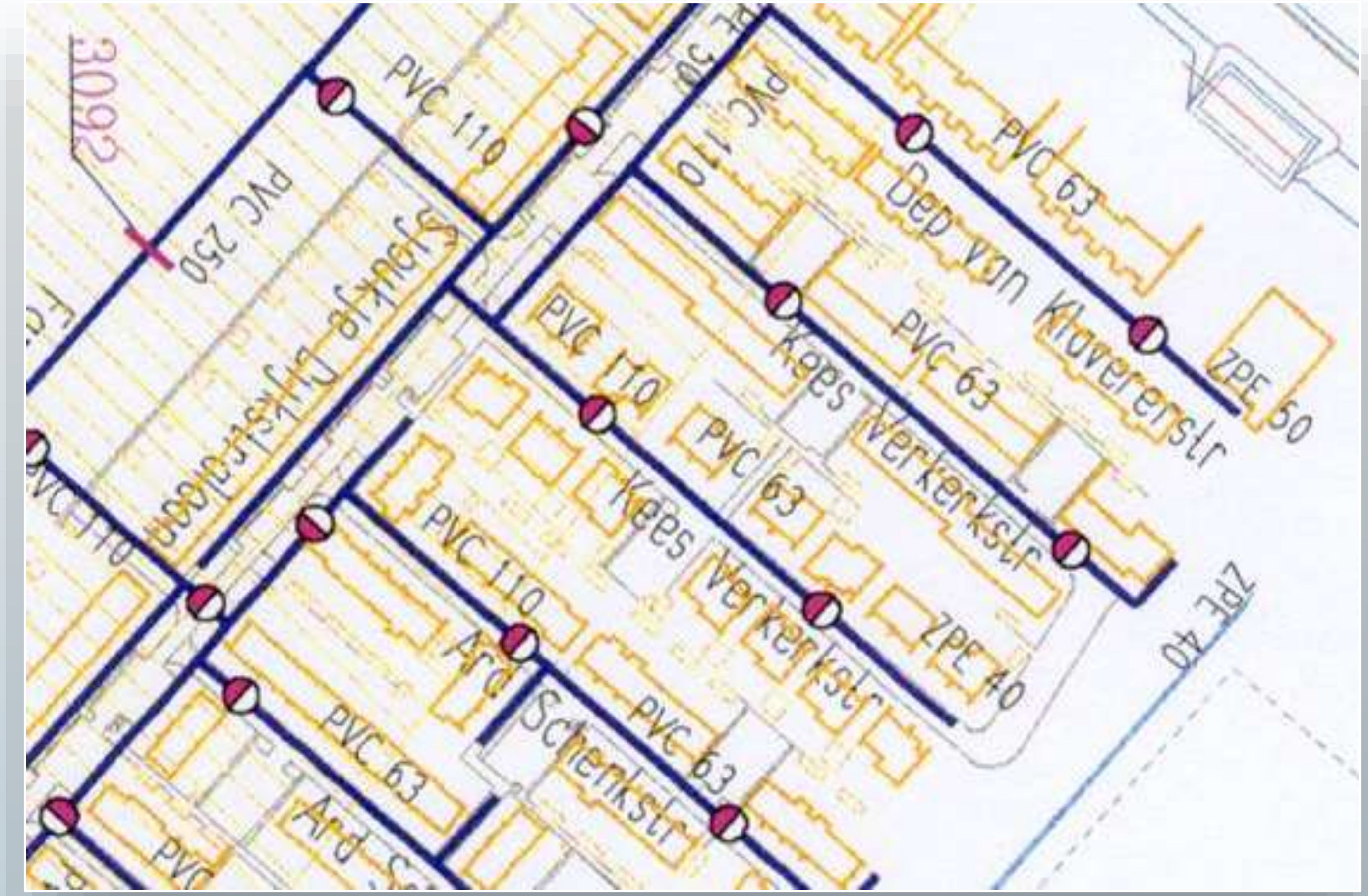
Examples

How to design a drinking water distribution system?

Designing self-cleaning networks

At the level of small distribution mains: design cheaper self-cleaning networks with highly reduced discolouration risks.

Minimum diameter in order to reach a certain flow velocity (0.2 – 0.25 m/s) during peak demands



The Dutch water companies

Since 2000 all Dutch water companies have been building self cleaning networks

Understanding demands = key + model required

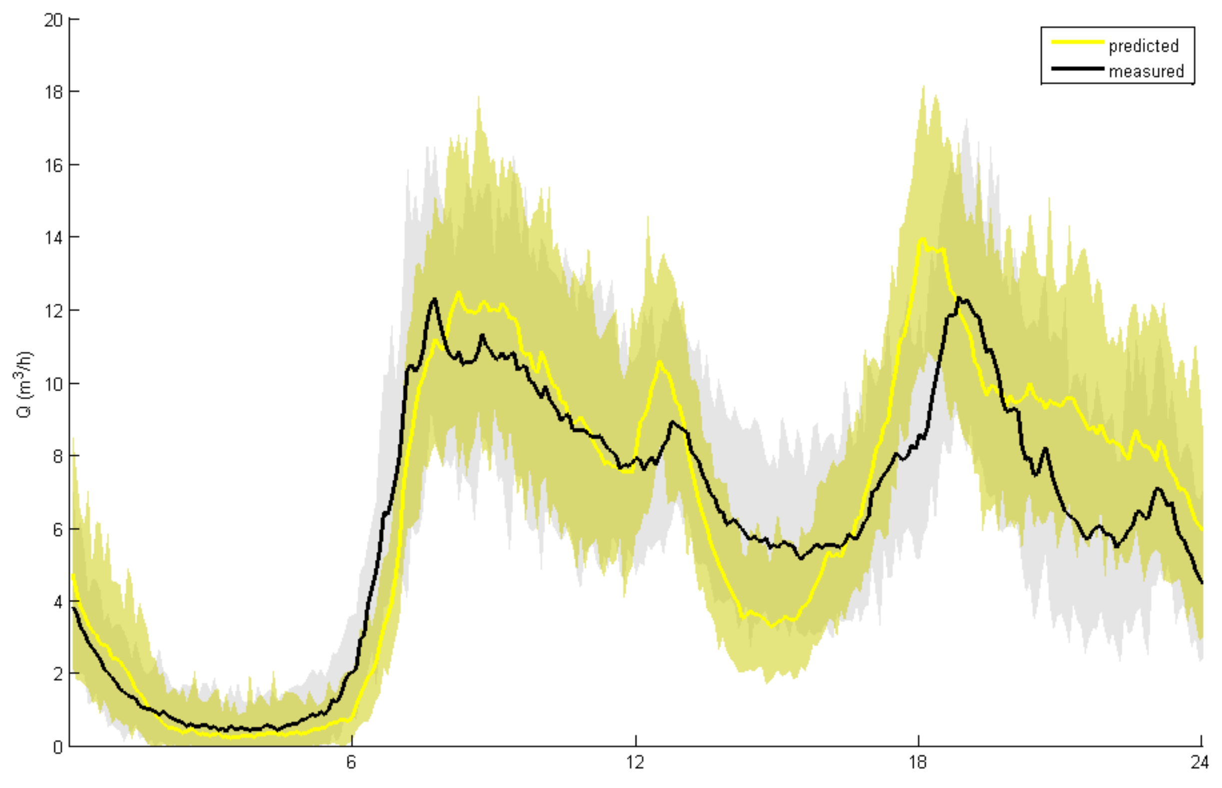
Examples

How to determine leakage in the system?

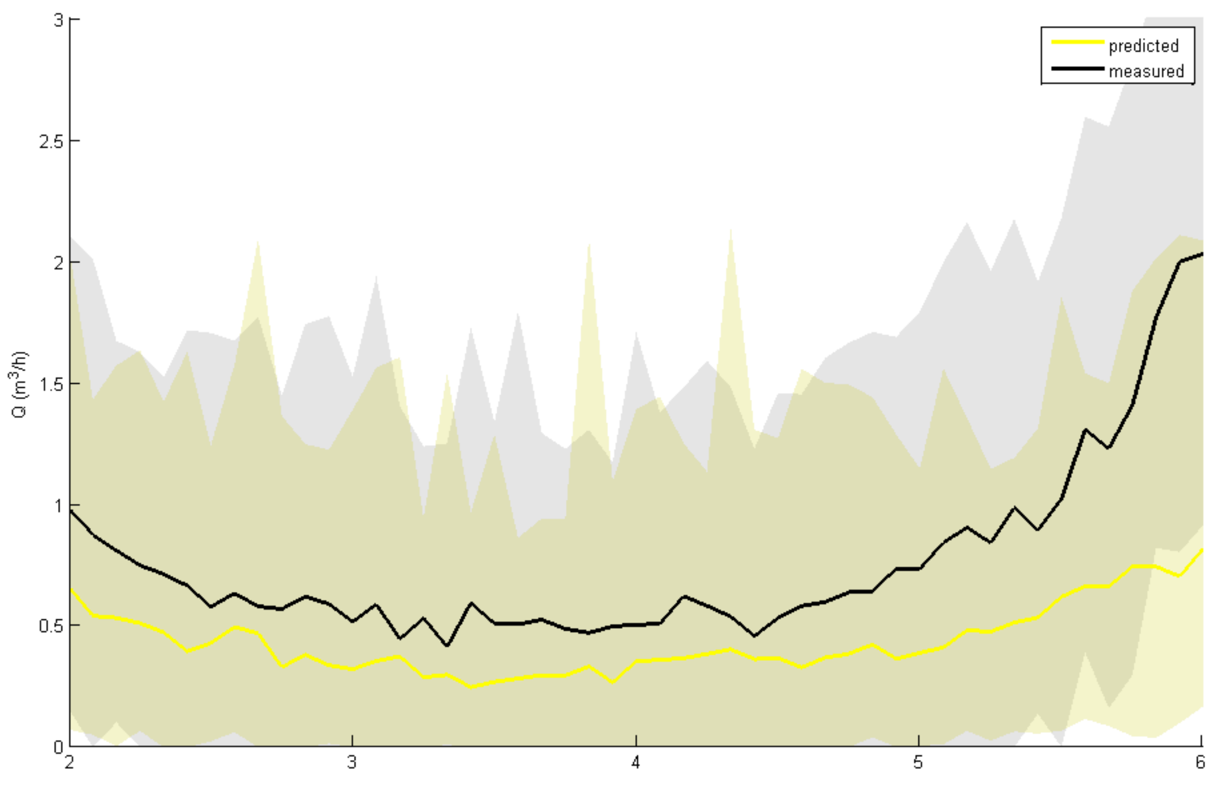
Night flow comparison

Predicted and measured night flow

DIURNAL PATTERNS



NIGHT FLOW

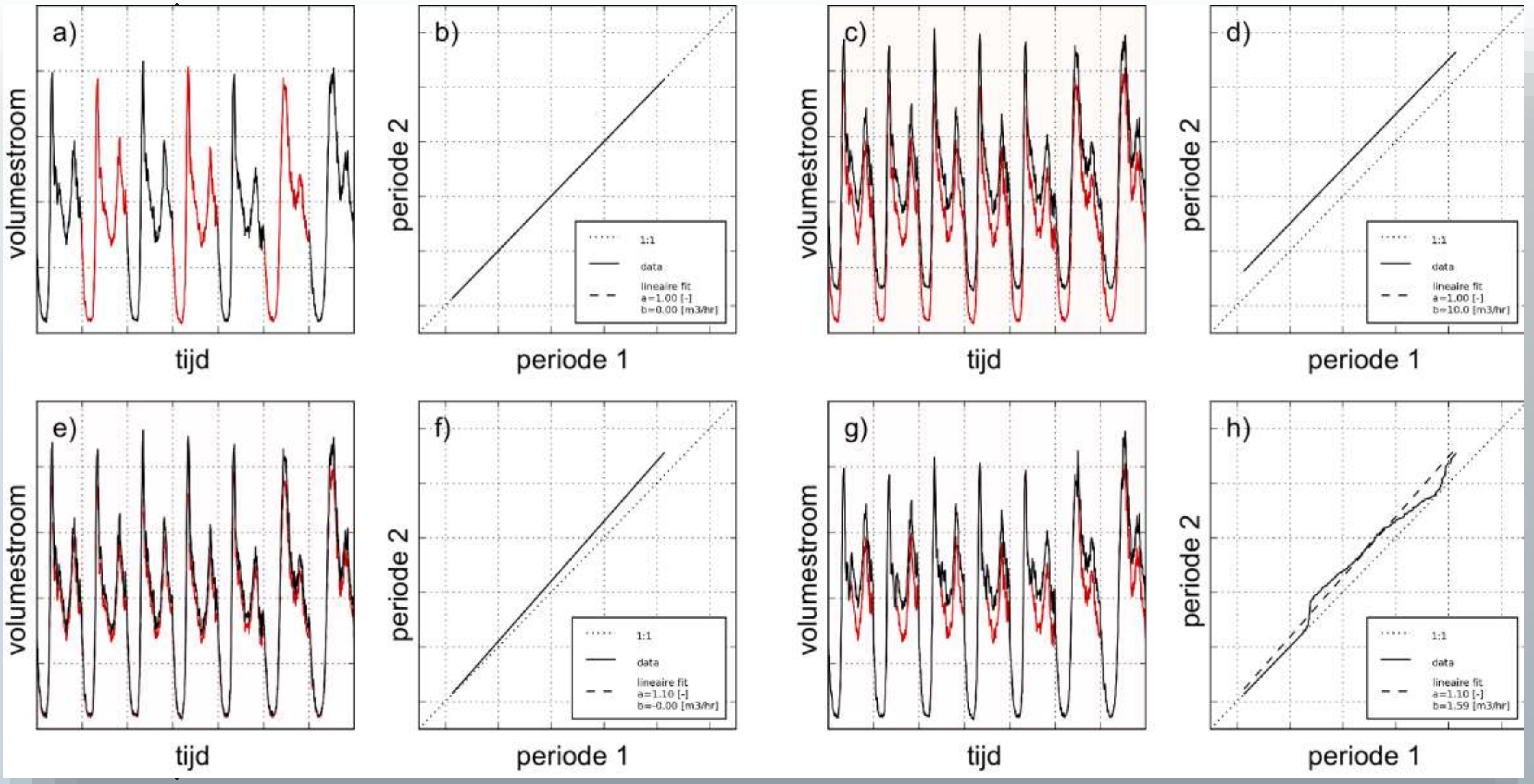


Comparison of Flow Pattern Distributions

Measured flows in various periods of time or DMA's

At the level of supply systems, like a DMA or number of DMA's, understanding demands may help to discern

- **consistent changes in demand, such as higher water demand during warmer weather,**
- **from inconsistent changes such as leaks.**



Understanding demands = key + model required

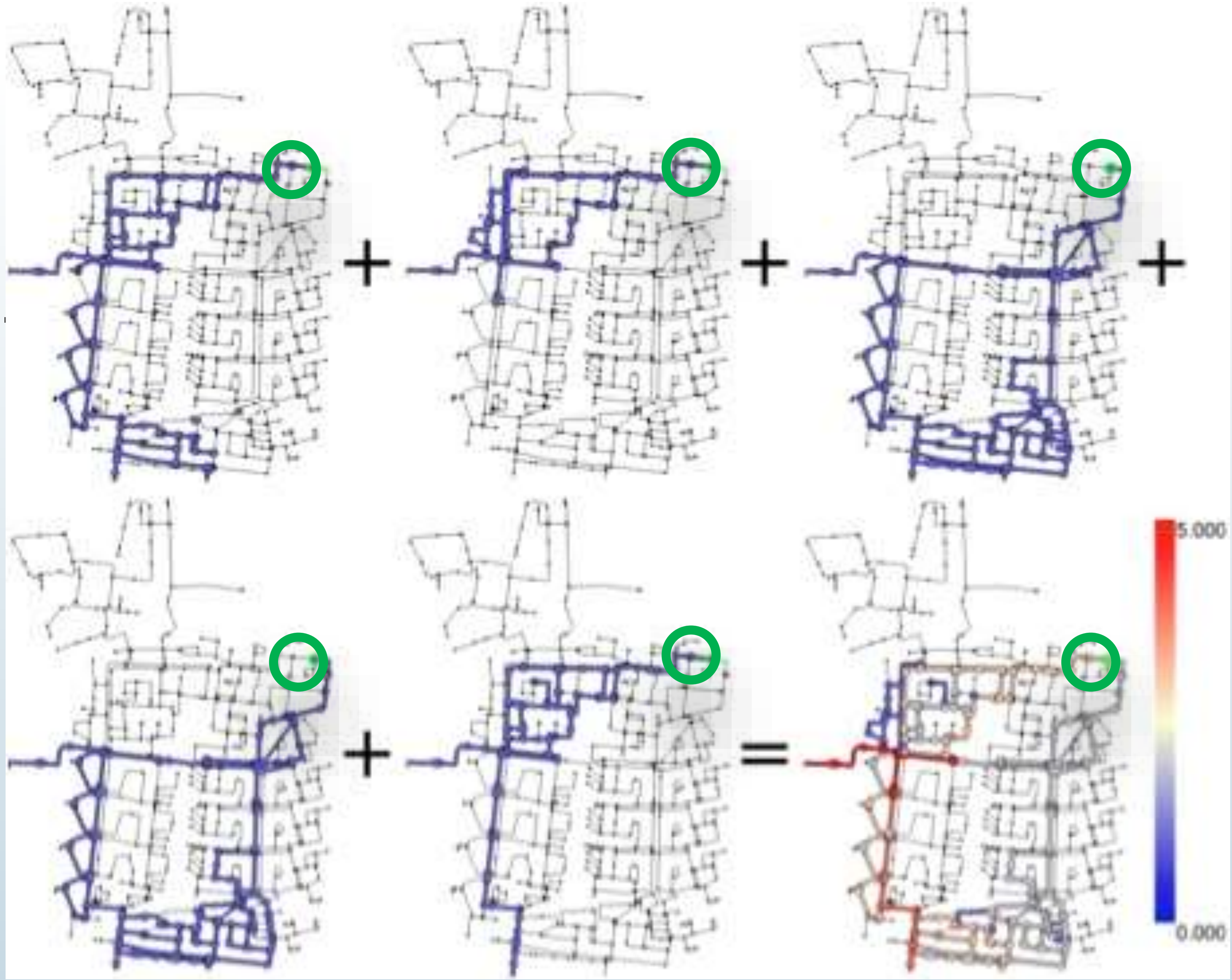
Examples

How to interpret sensor data?

Backtracing with stochastic demands

Different sets of demand patterns would lead to a different path of the water towards the demand nodes and potential sensor locations.

Interpretation of the sensor reading depends on the “known” demands.



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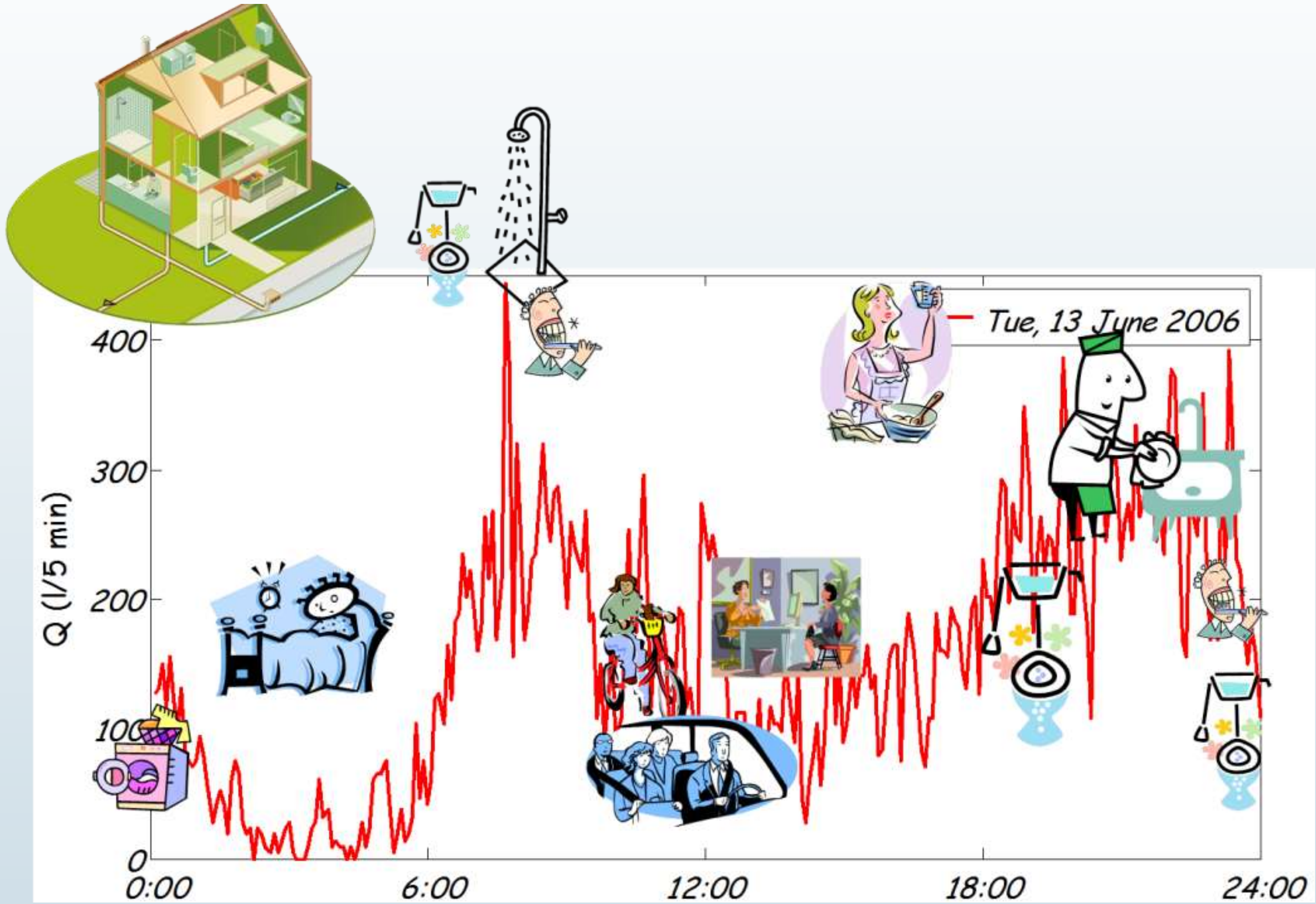
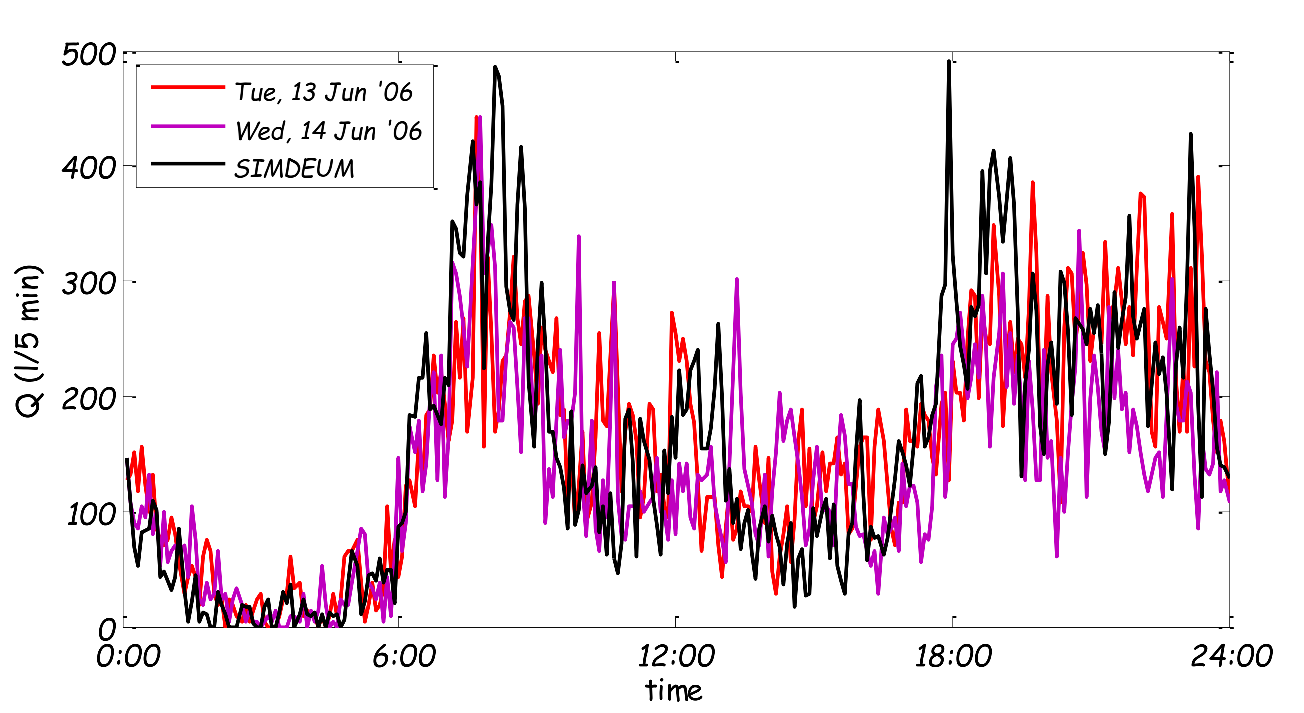
Stochastic nature of water demand

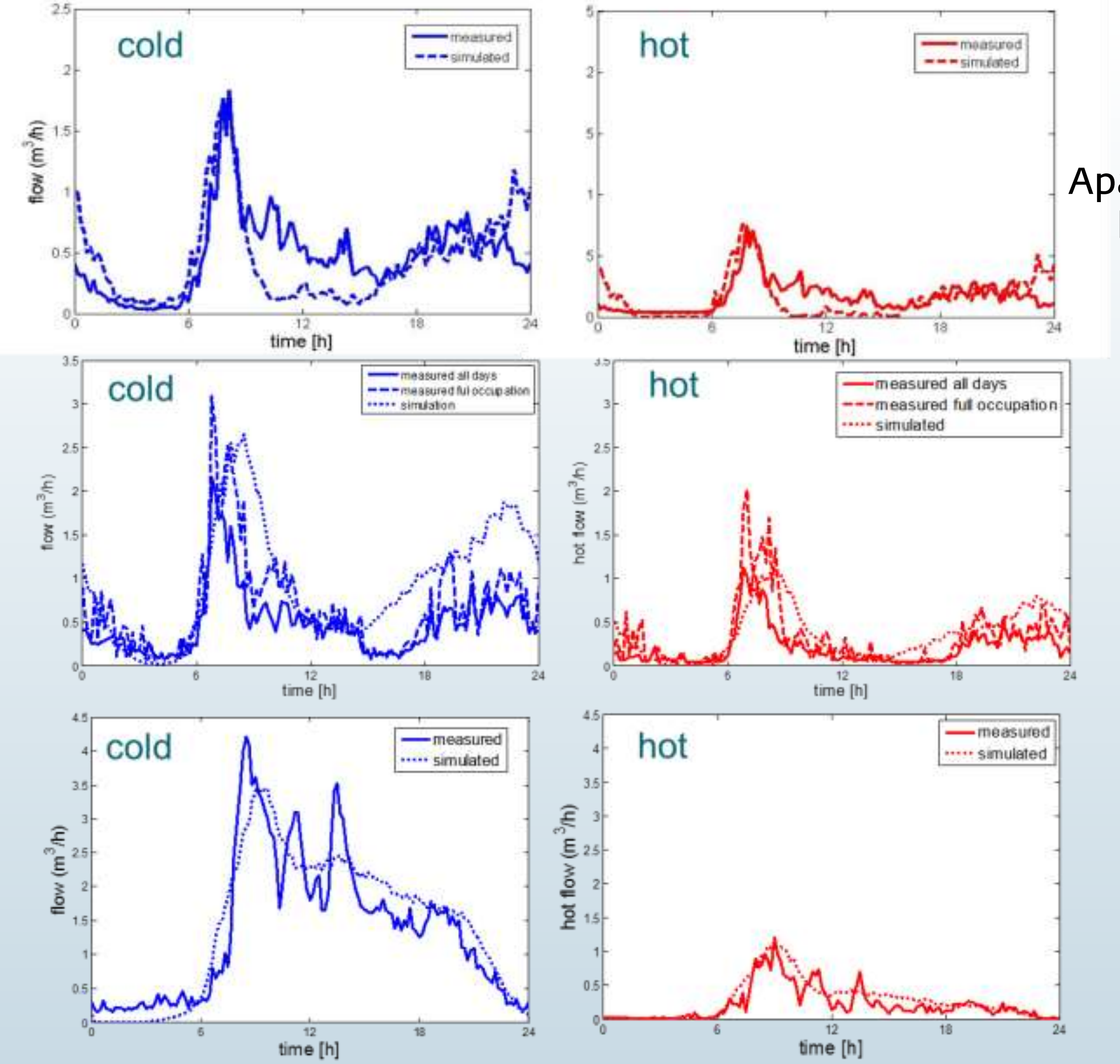
Since water use is stochastic in nature, a model is required to help to understand what drives the demands and how demand influences processes on various levels.



Stochastic nature of water demand

SIMDEUM® as a model





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Hotel

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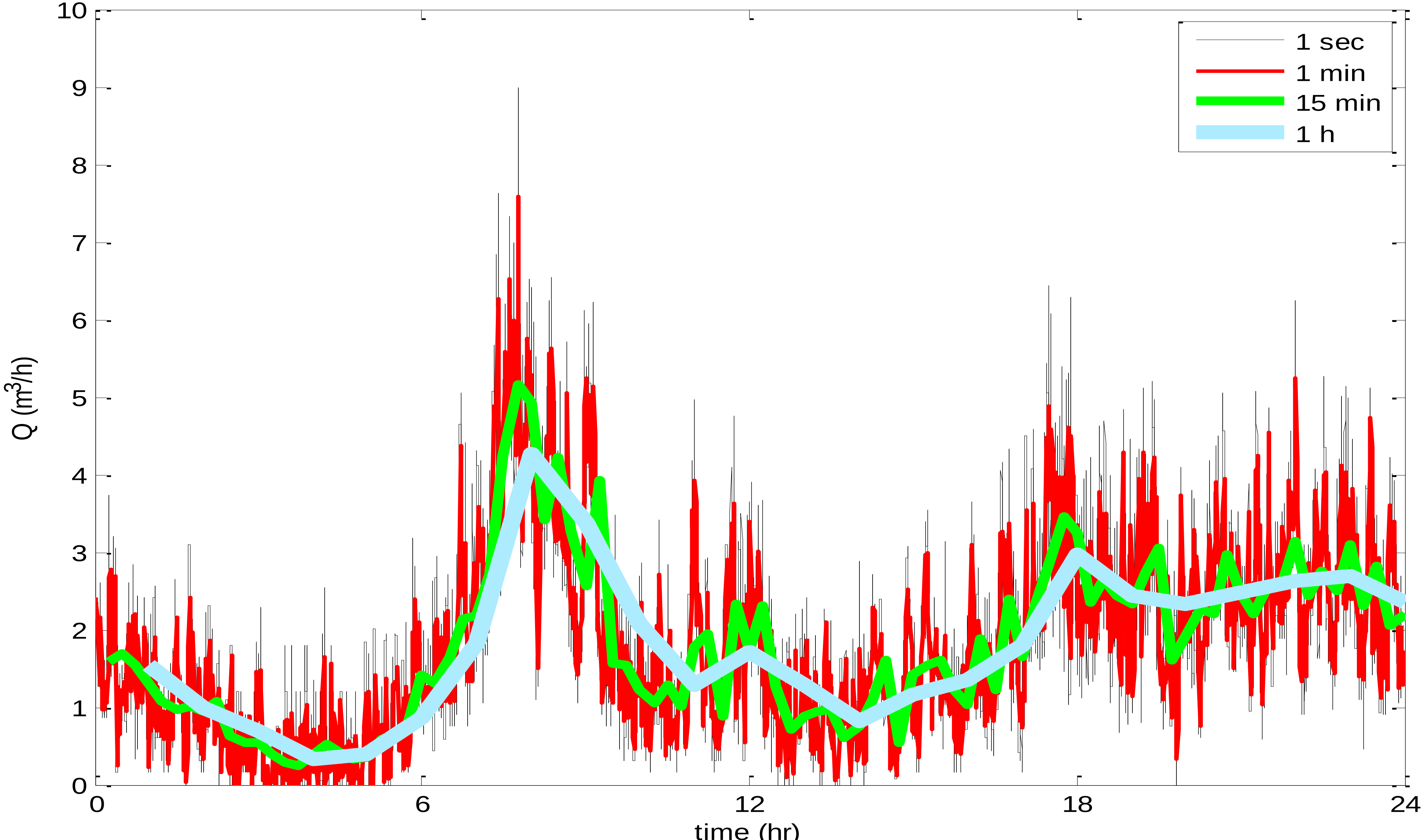
Hydraulic network models

Level of detail?

- Spatial scale
- Temporal scale

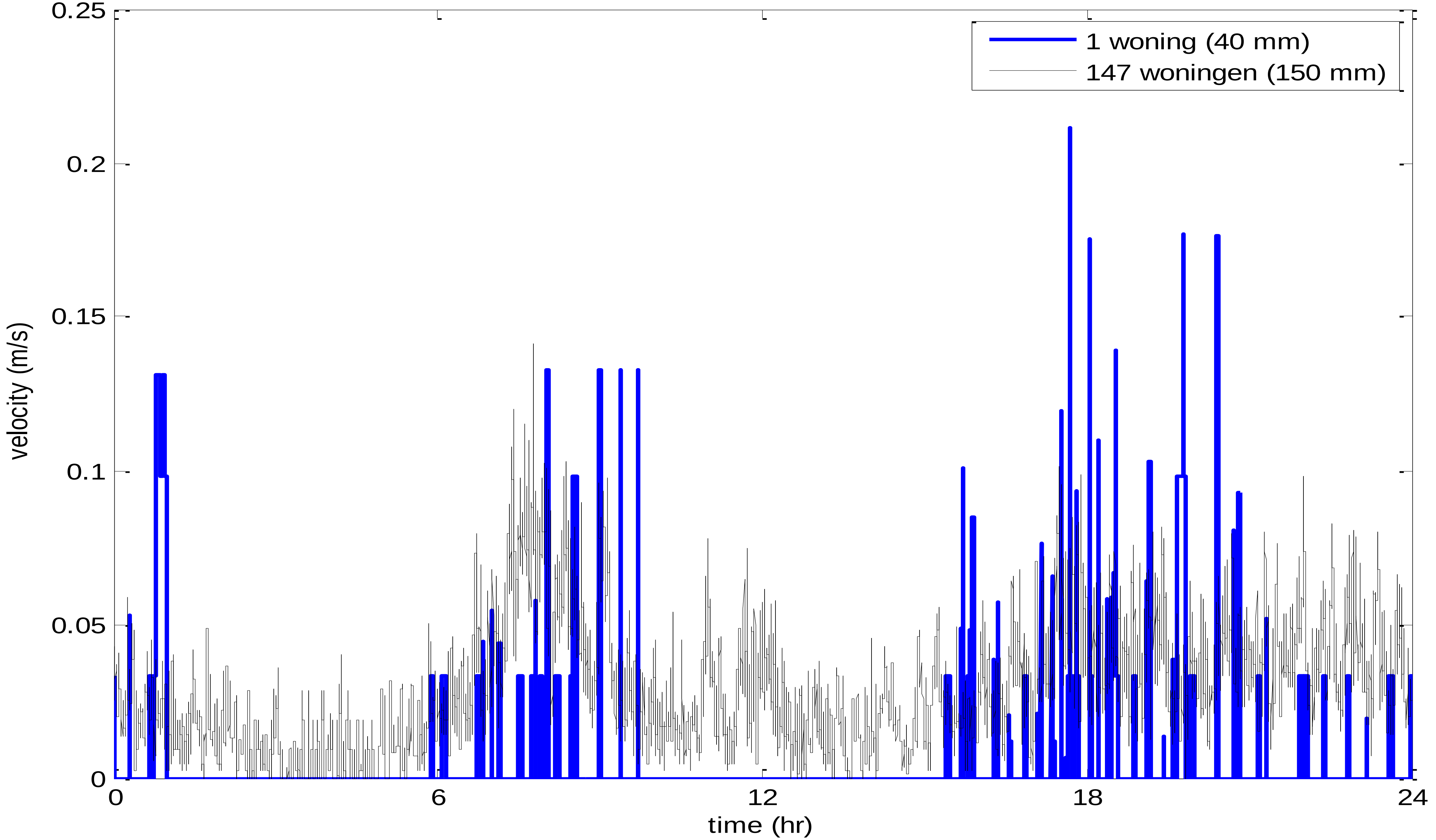
Importance of temporal scale

Probability of stagnant water, laminar and turbulent flow

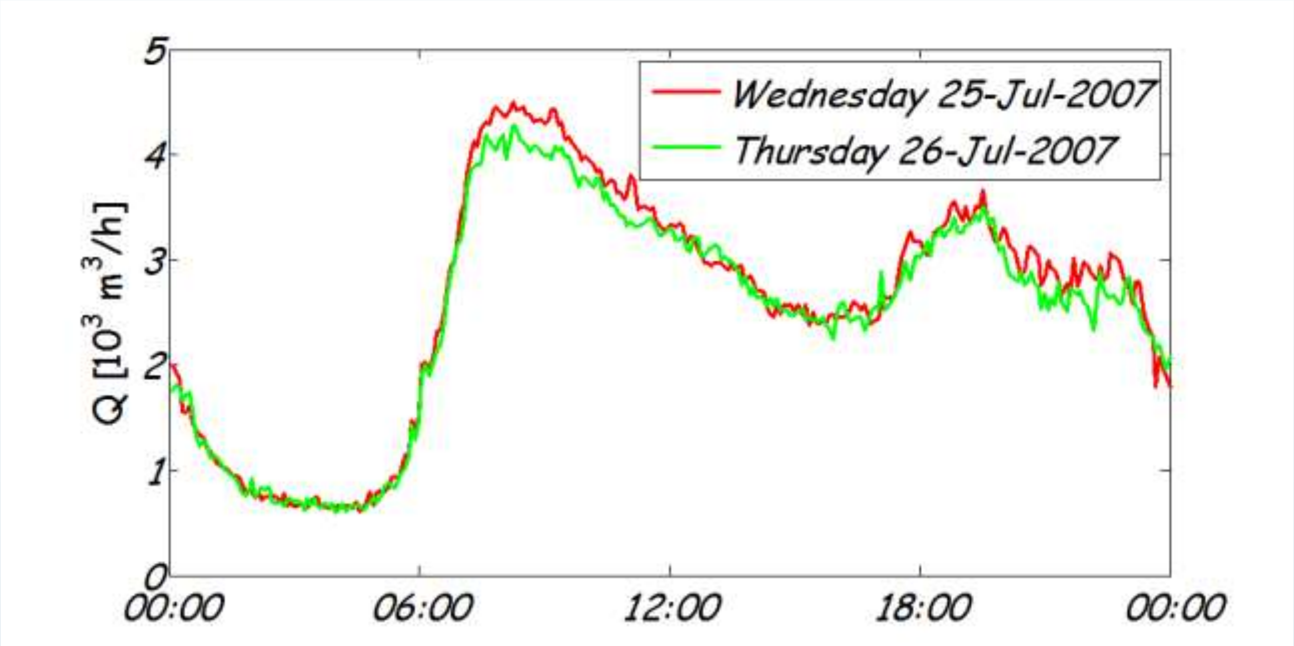


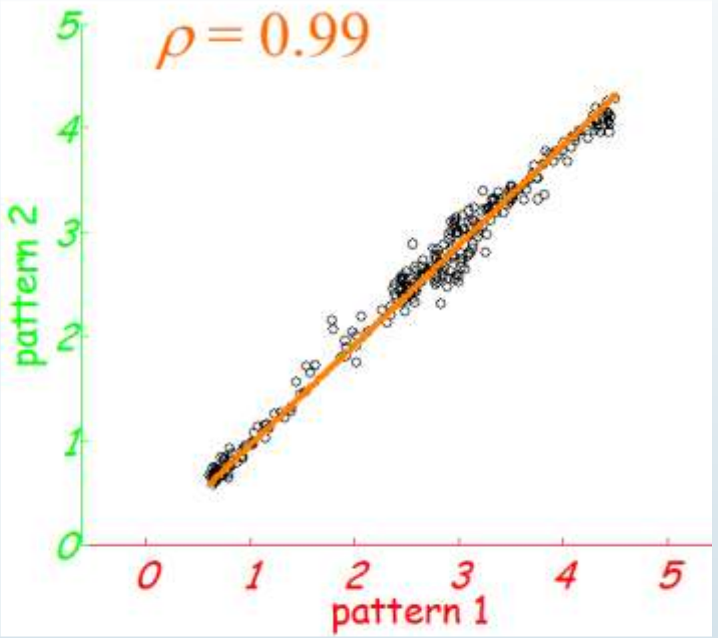
Importance of spatial scale

Probability of stagnant water, laminar and turbulent flow

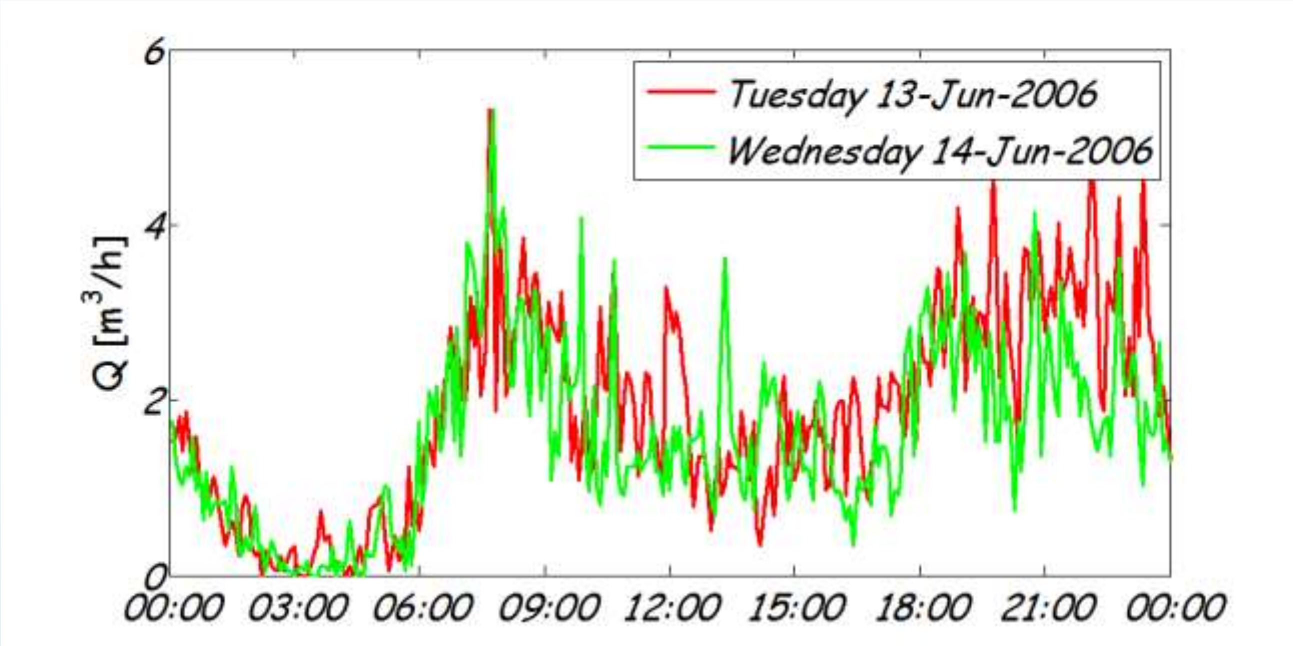


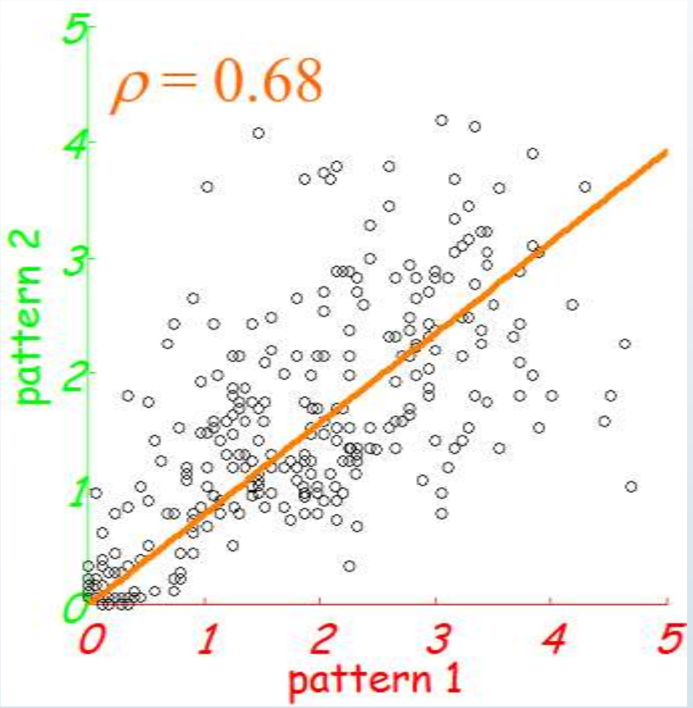
Correlation between days / supply area



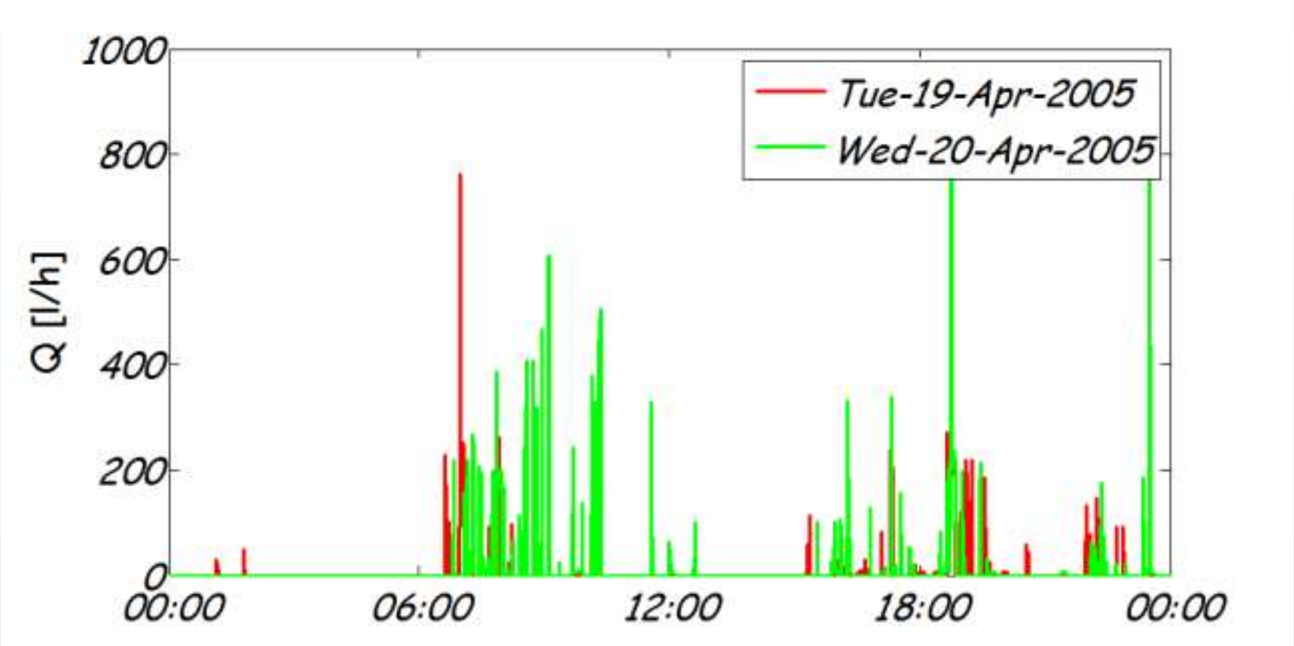


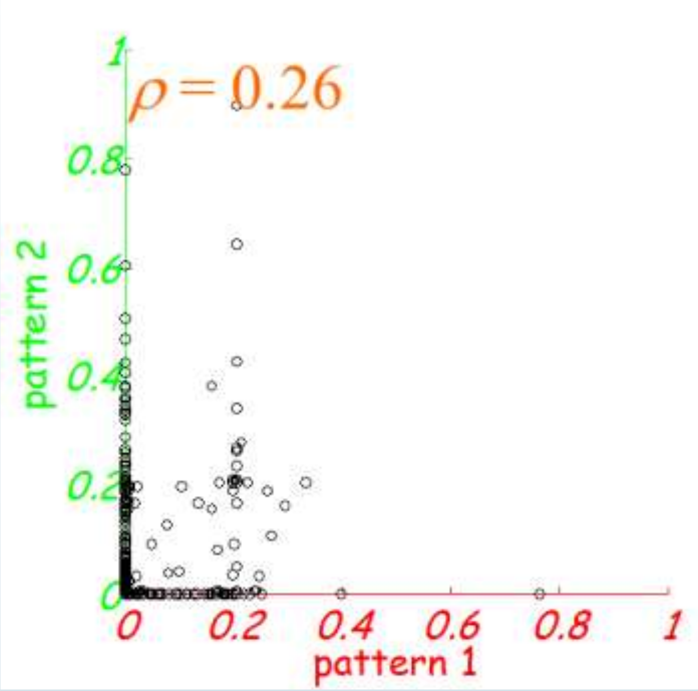
Correlation between days / 150 homes





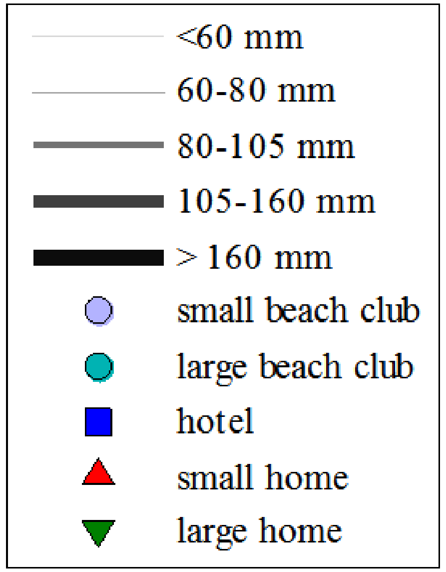
Correlation between days / individual home

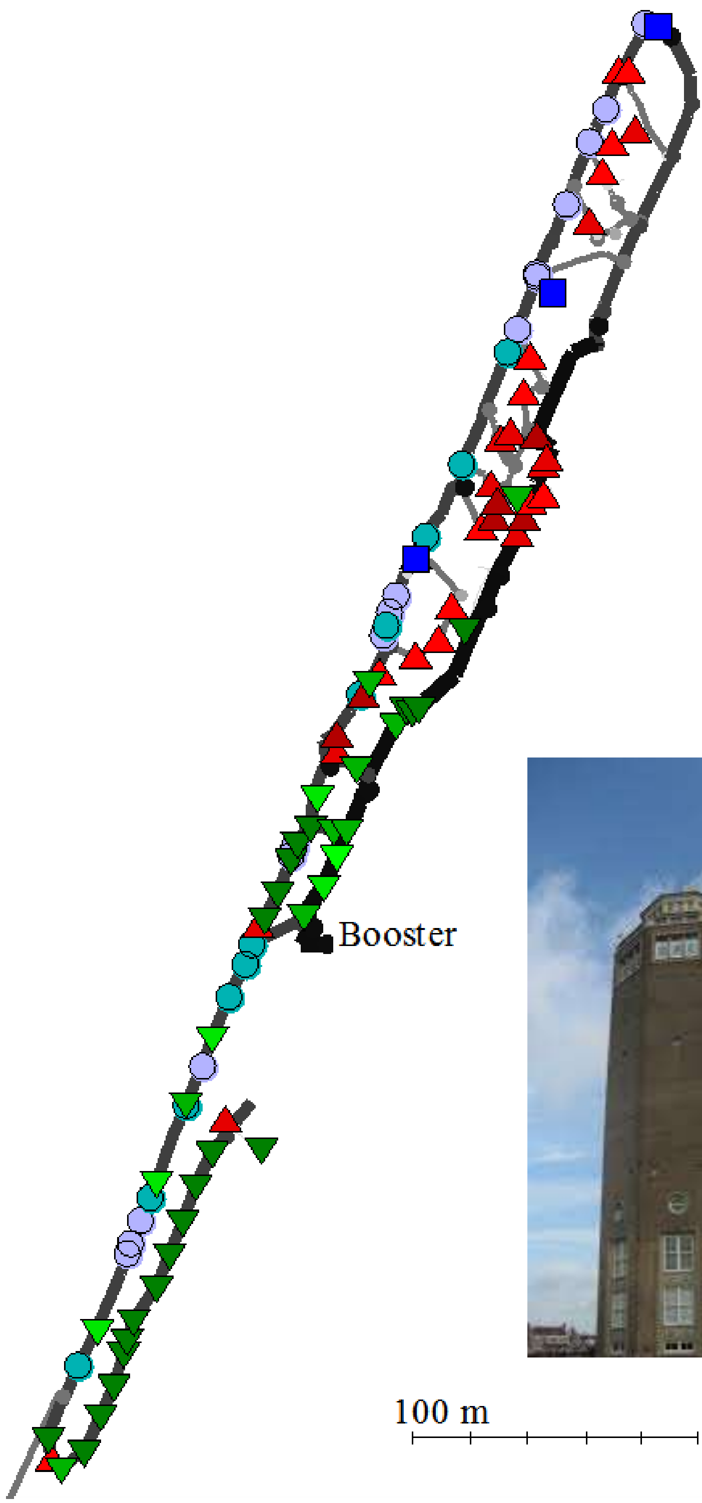


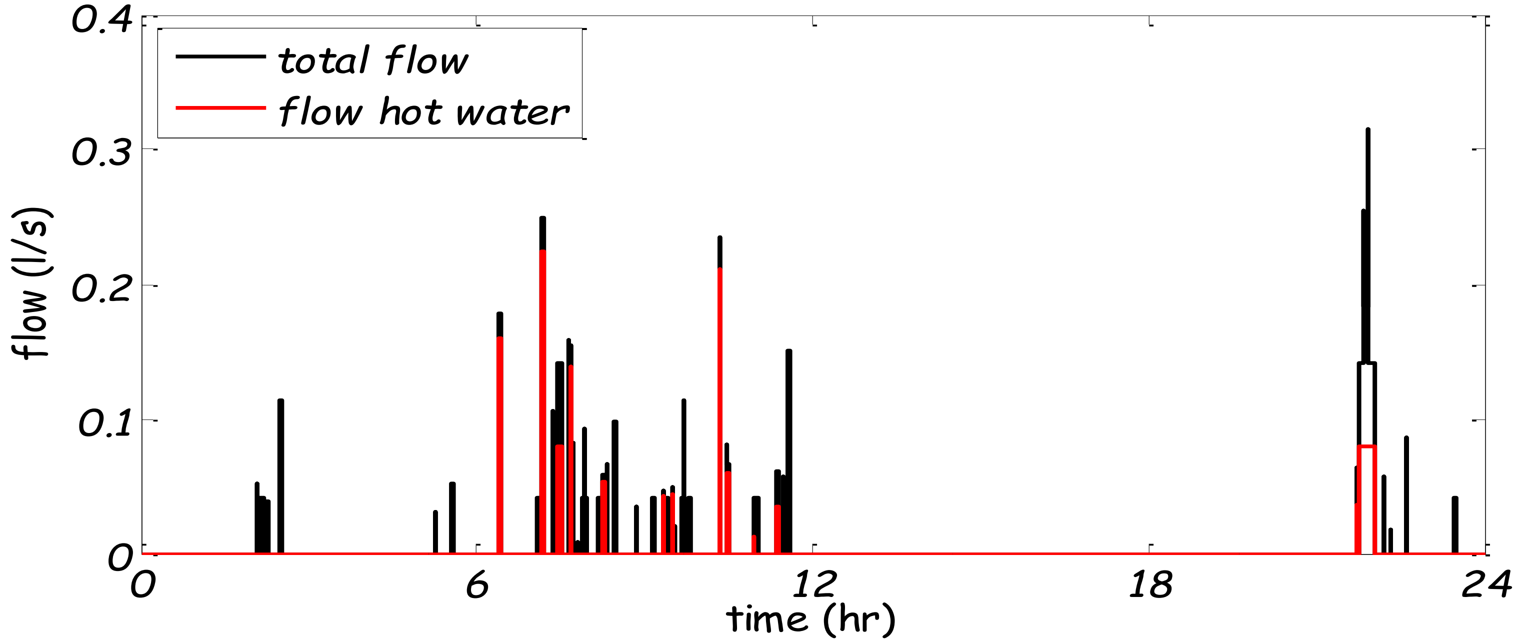


Hydraulic network model:

top-down or bottom-up?







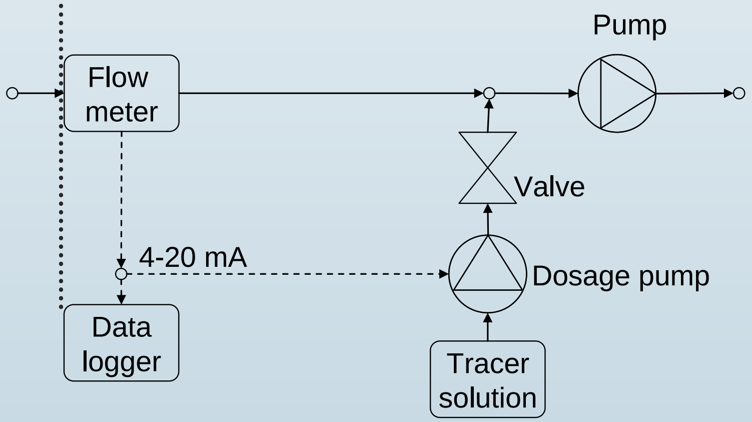
Zandvoort test area

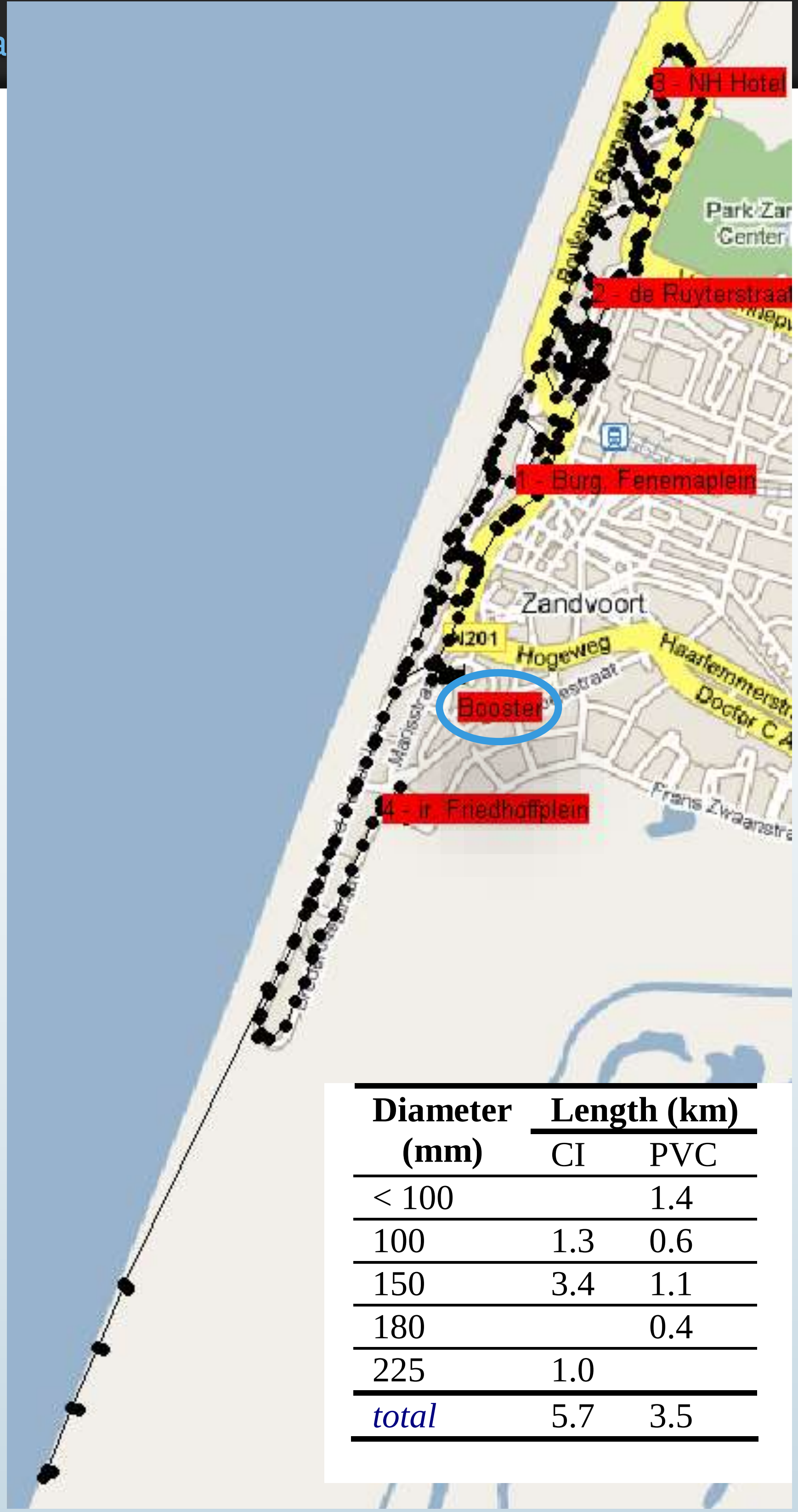
Booster

- Added NaCl, 3 hours on, 20 hours off
- Measured Q

Locations 1-4

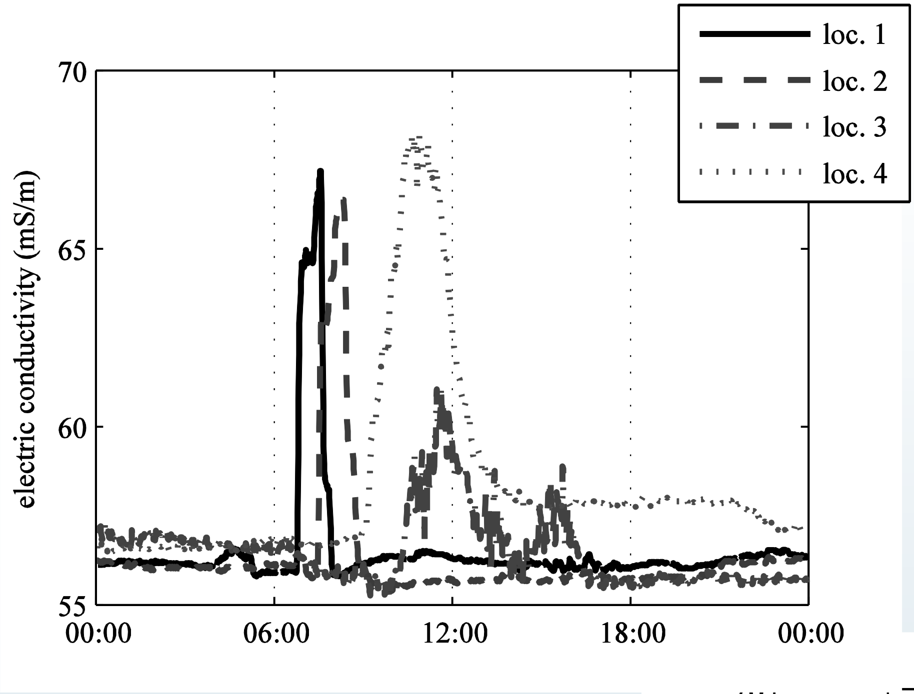
- Measured EC
- Q (location 3 only)

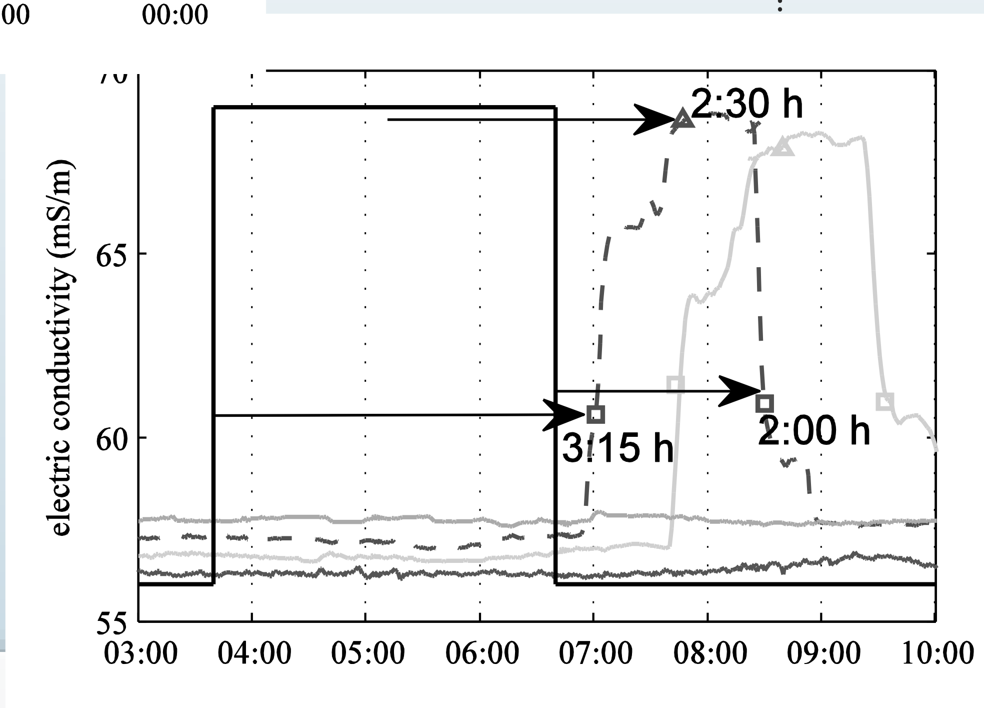


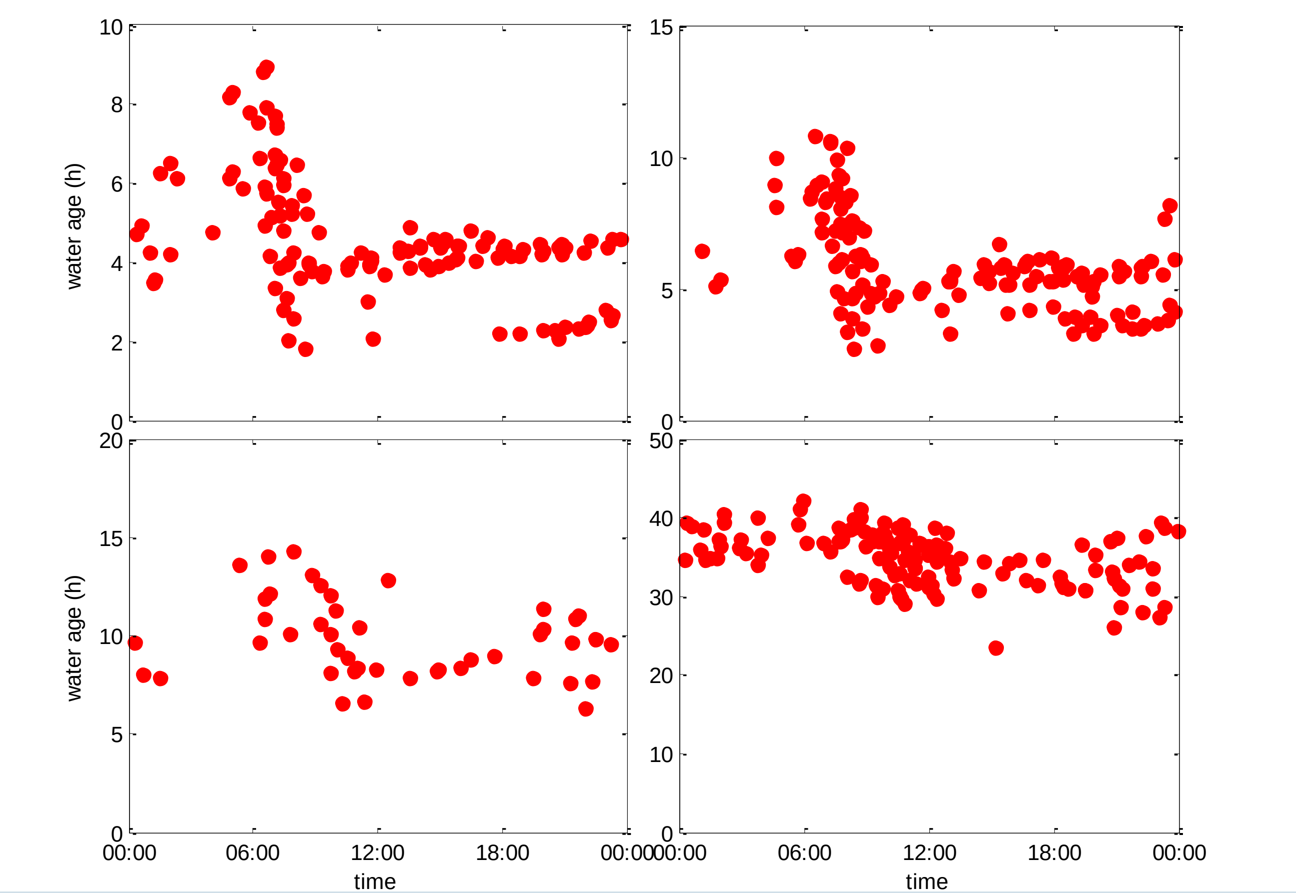


Diameter (mm)	Length (km) CI	PVC
< 100		1.4
100	1.3	0.6
150	3.4	1.1
180		0.4
225	1.0	
total	5.7	3.5

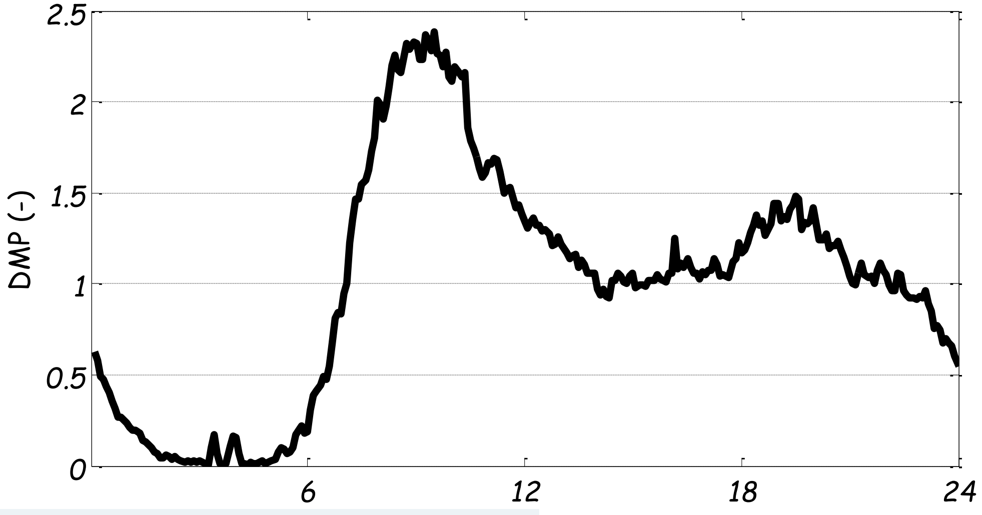
From EC to travel times

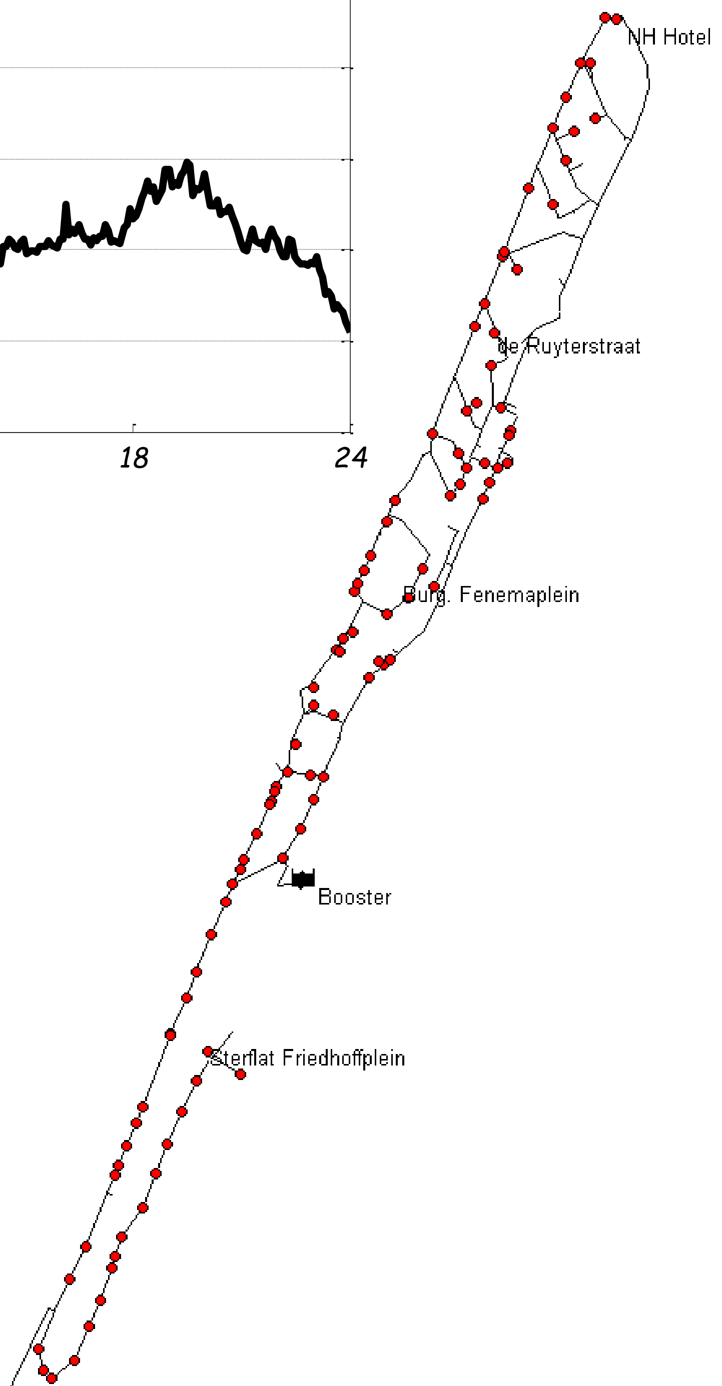


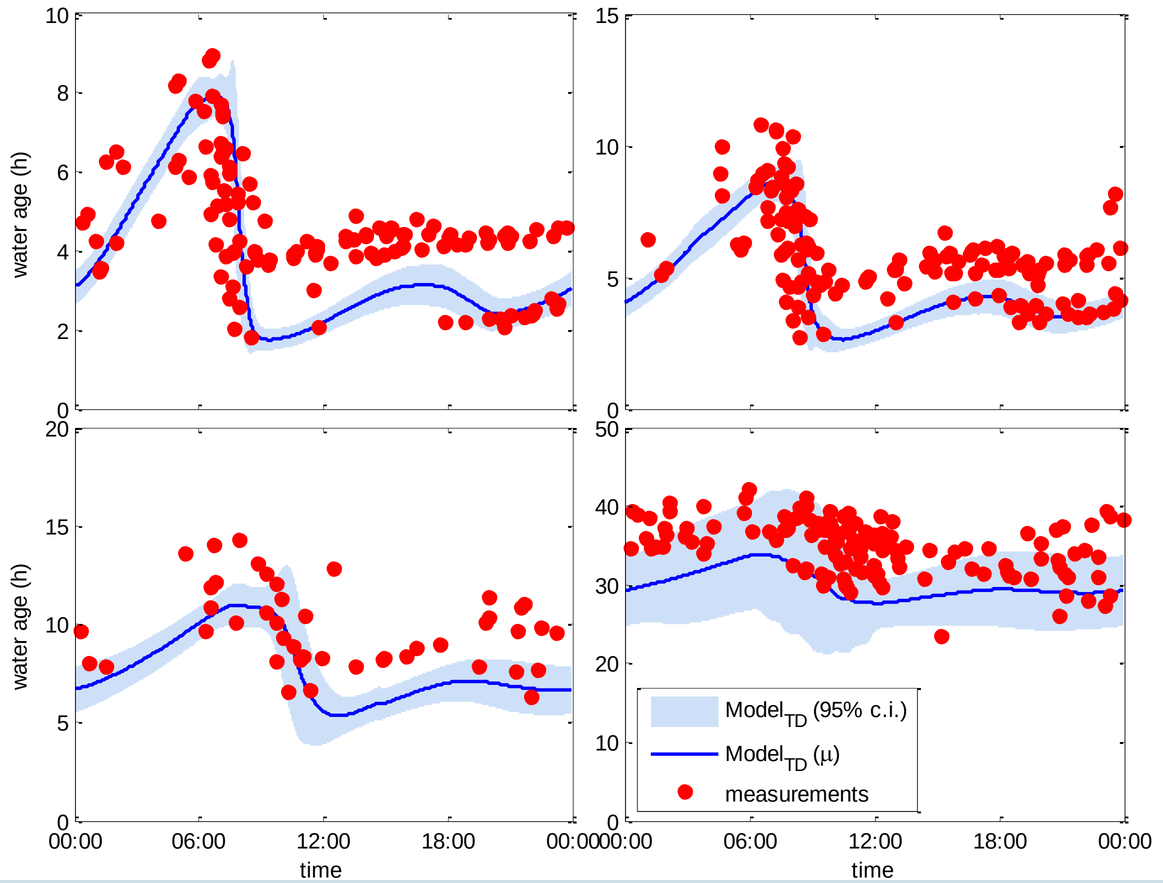




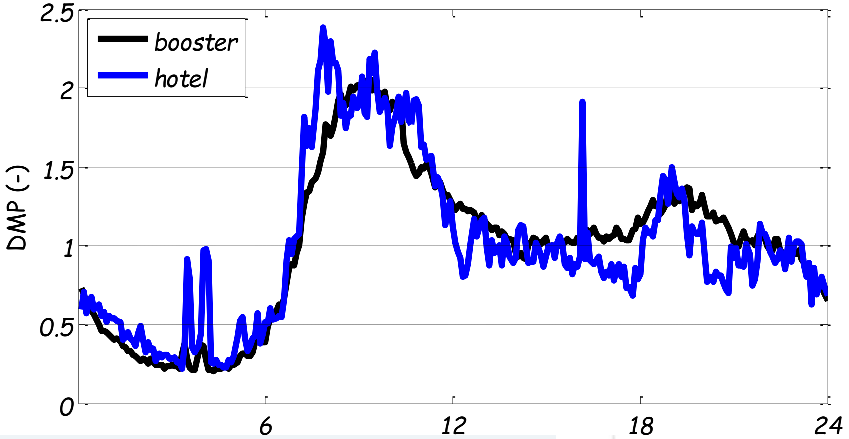
Top down demand allocation

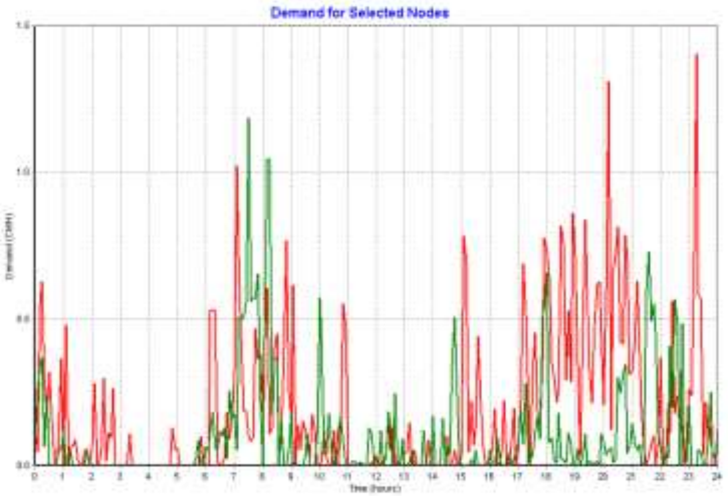


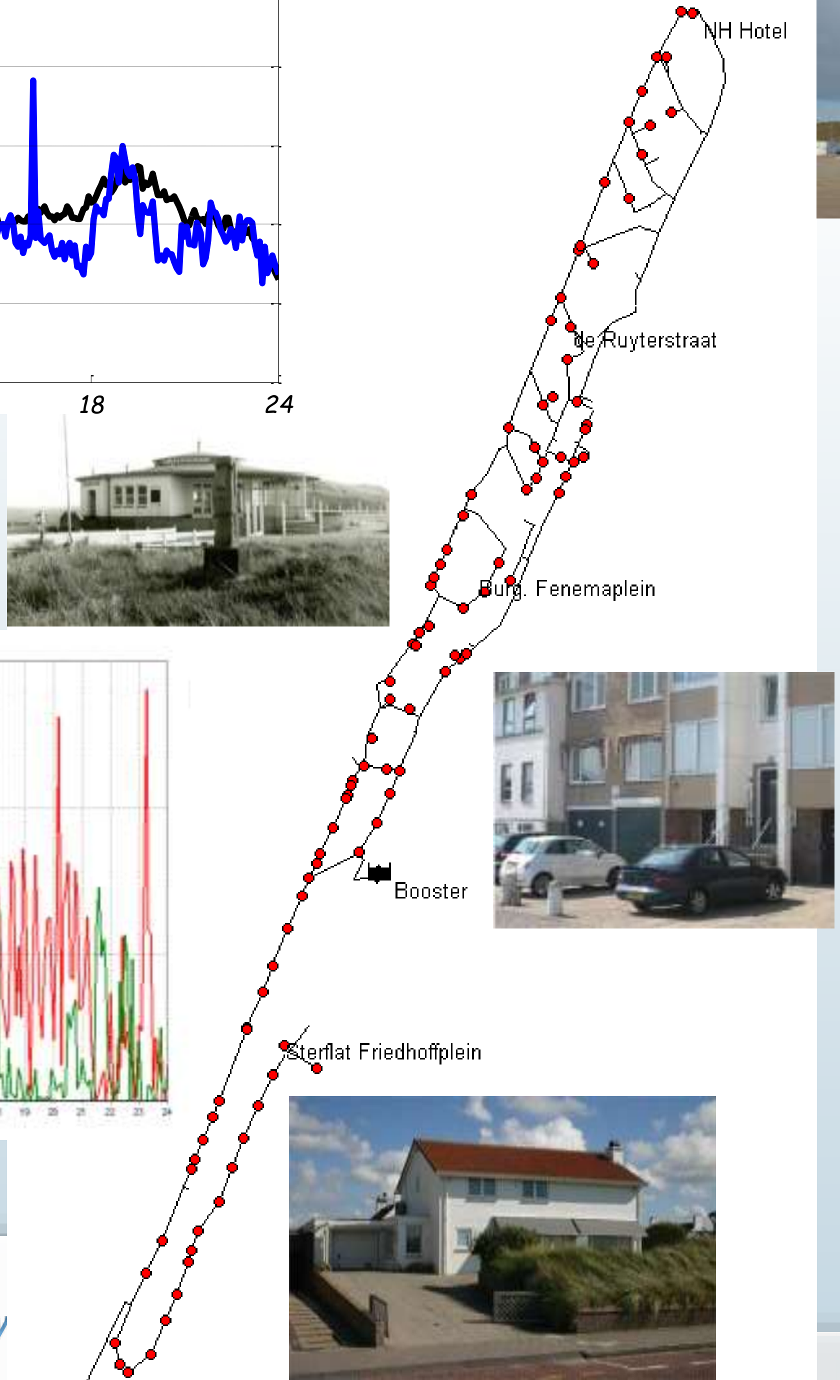


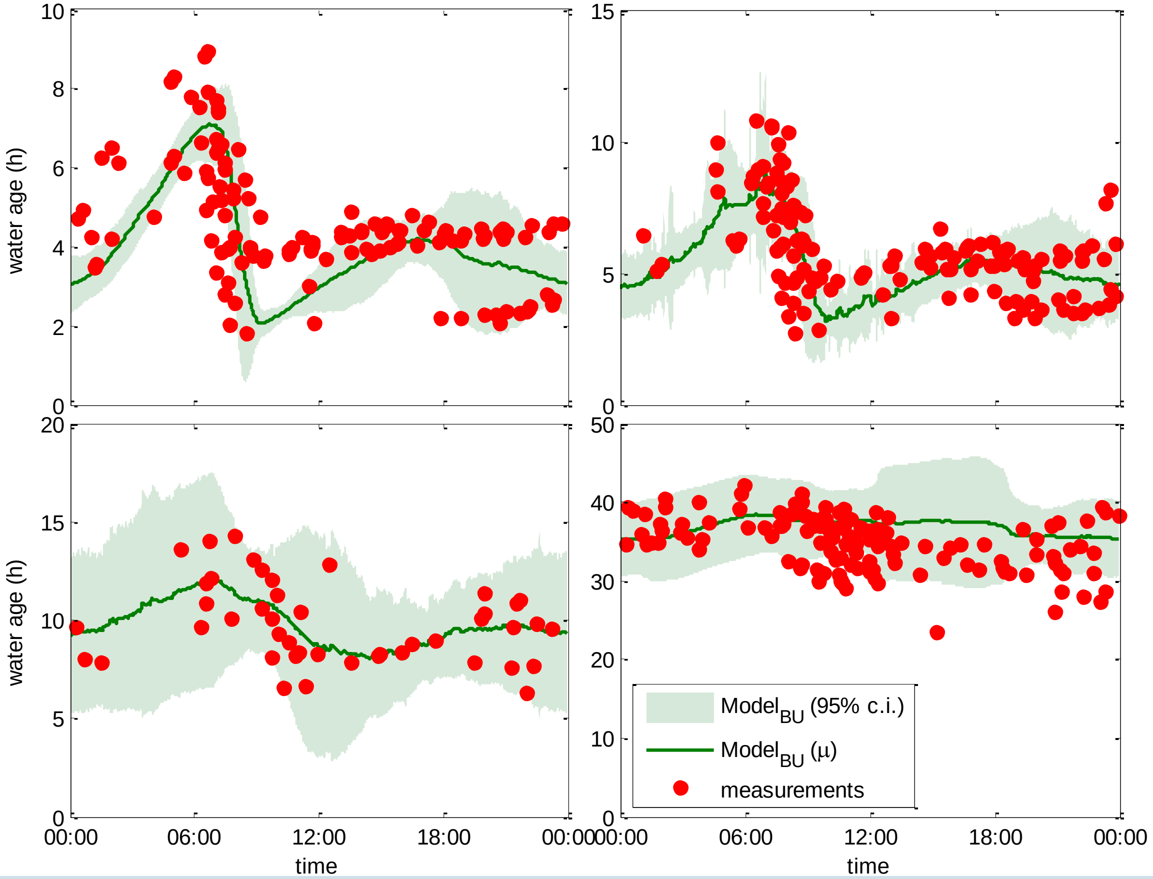


Bottom-up demand allocation









KWR Watercy

My message

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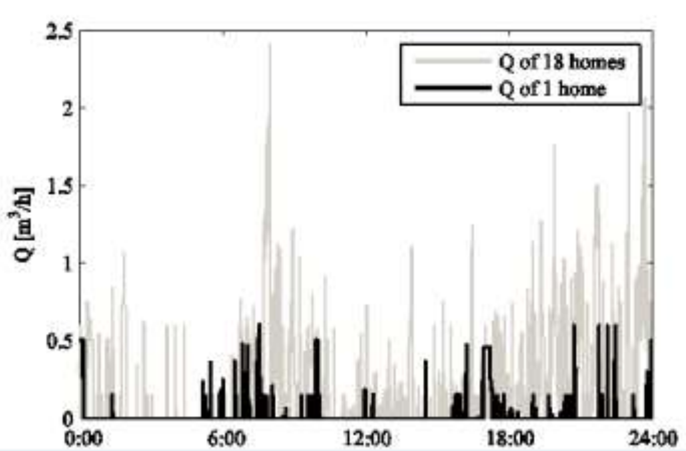
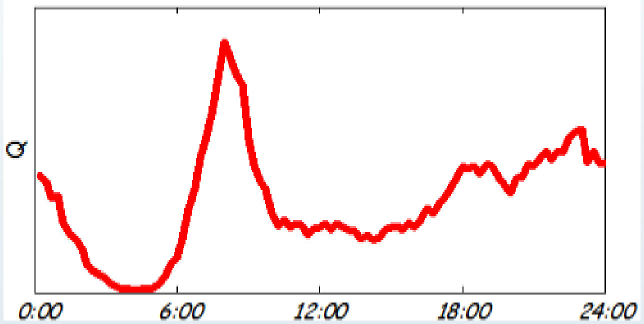
Hydraulic network models

Effect of top-down versus bottom-up demand allocation



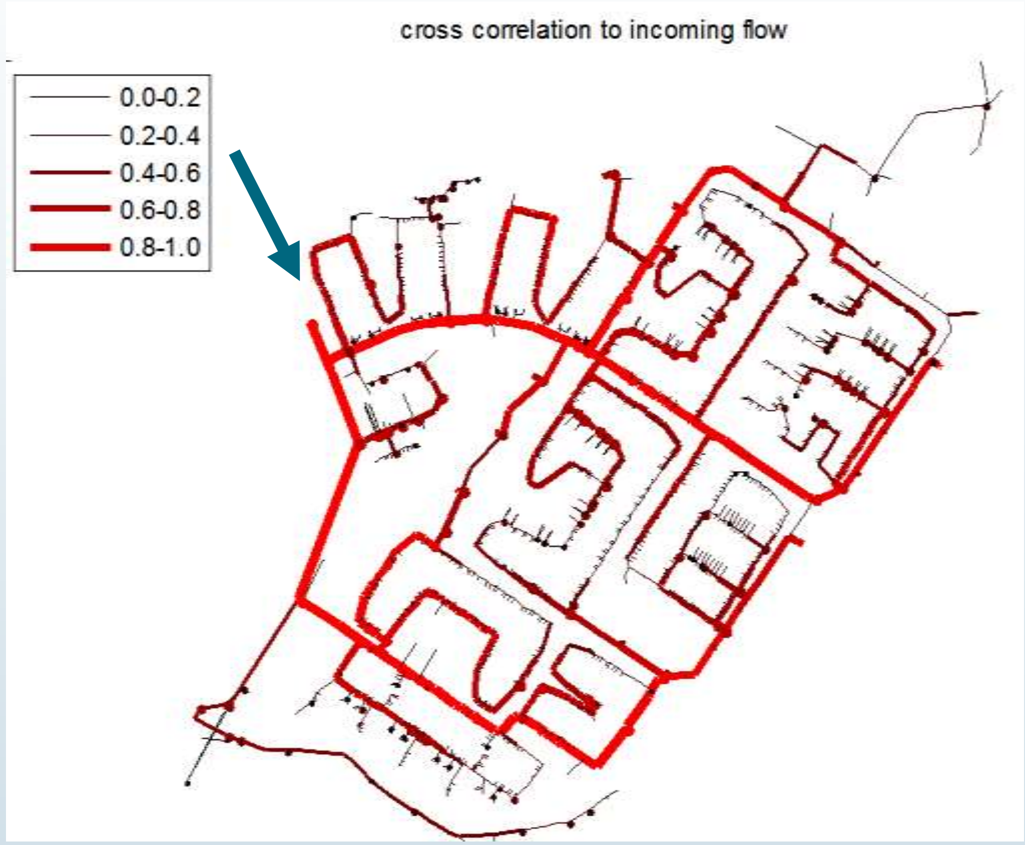
bottom-up model (SIMDEUM)

top-down model



Cross correlation with incoming flow

BOTTOM-UP MODEL

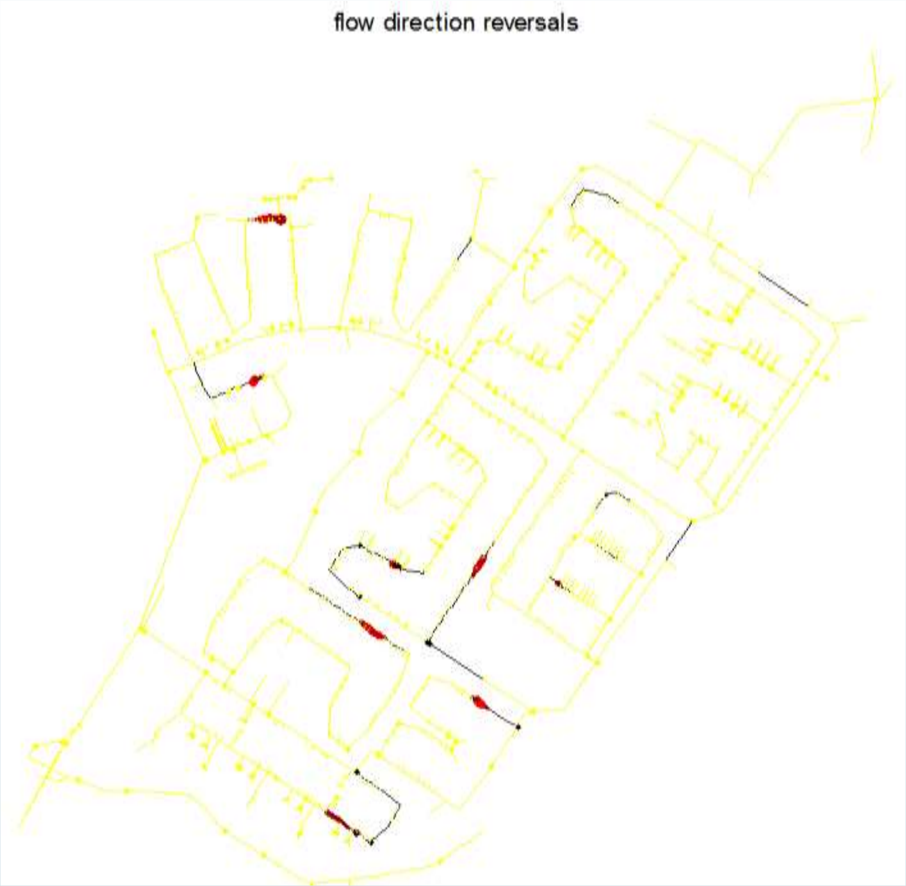


TOP-DOWN MODEL

Flow direction reversals

BOTTOM-UP MODEL

TOP-DOWN MODEL



% of stangnant flow (per day)

BOTTOM-UP MODEL

TOP-DOWN MODEL

% of laminar flow (per day)

BOTTOM-UP MODEL

TOP-DOWN MODEL

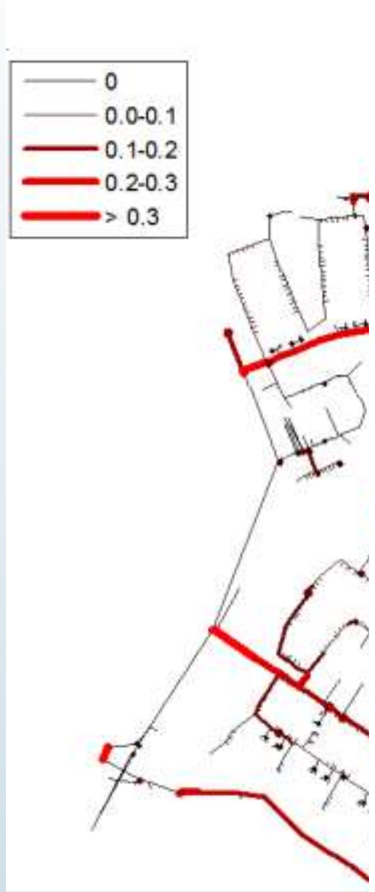
% of turbulent flow (per day)

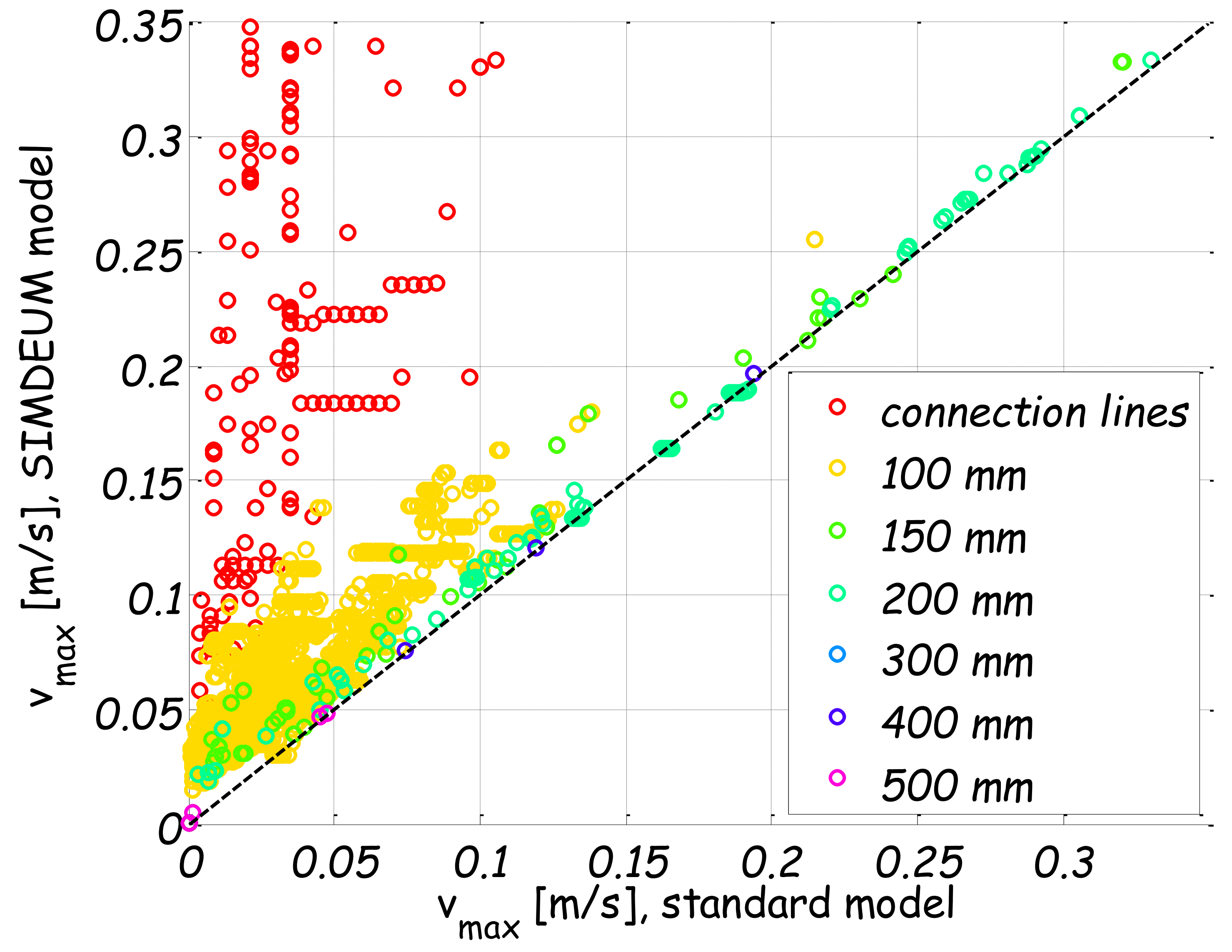
BOTTOM-UP MODEL

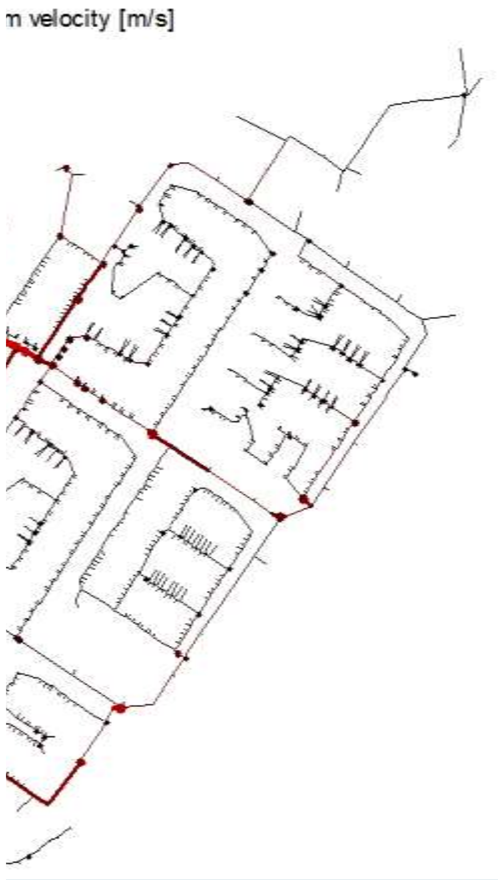
TOP-DOWN MODEL

Max flow velocities

BOTTOM-UP MODEL

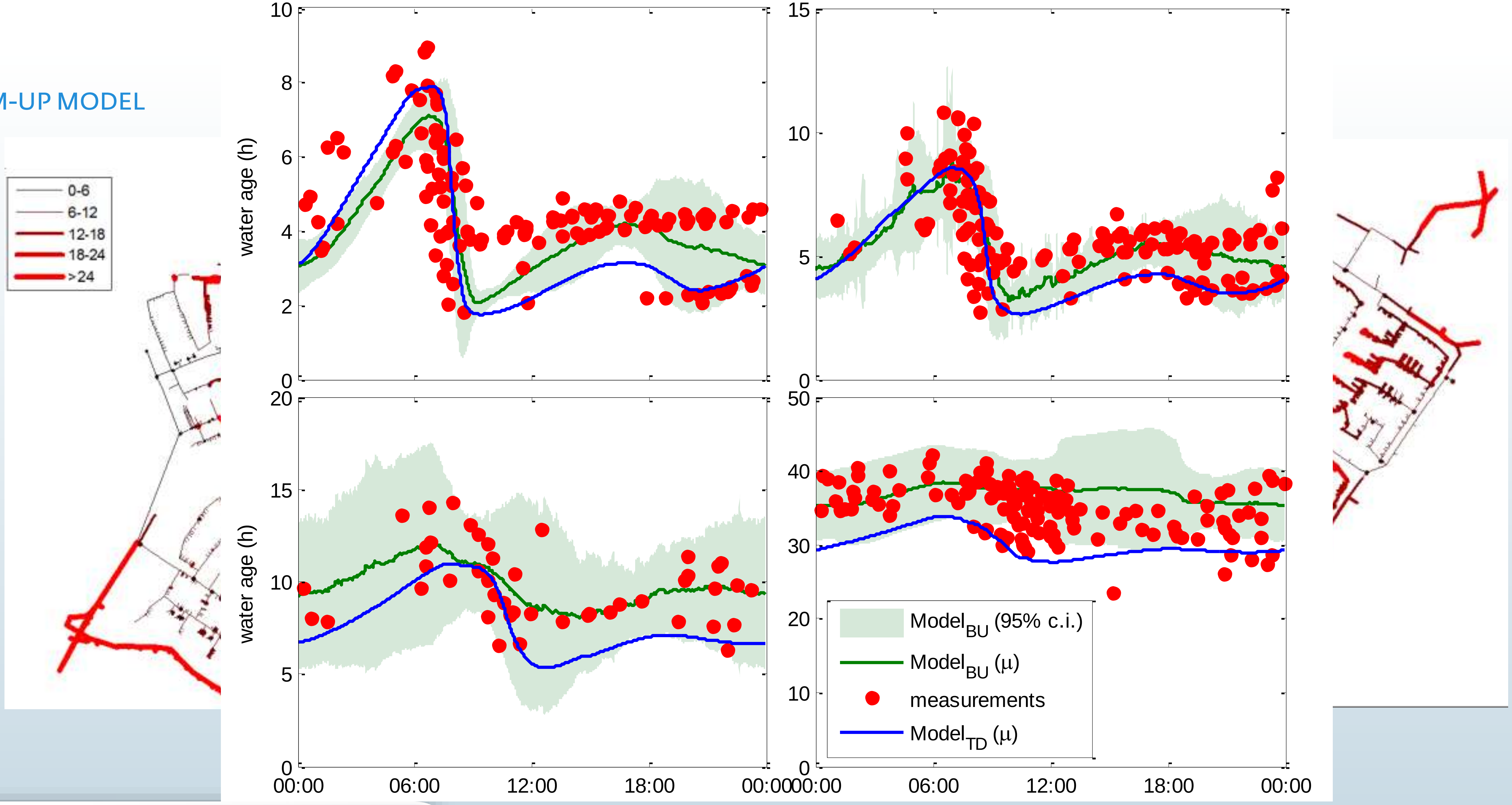






Residence times

BOTTOM-UP MODEL



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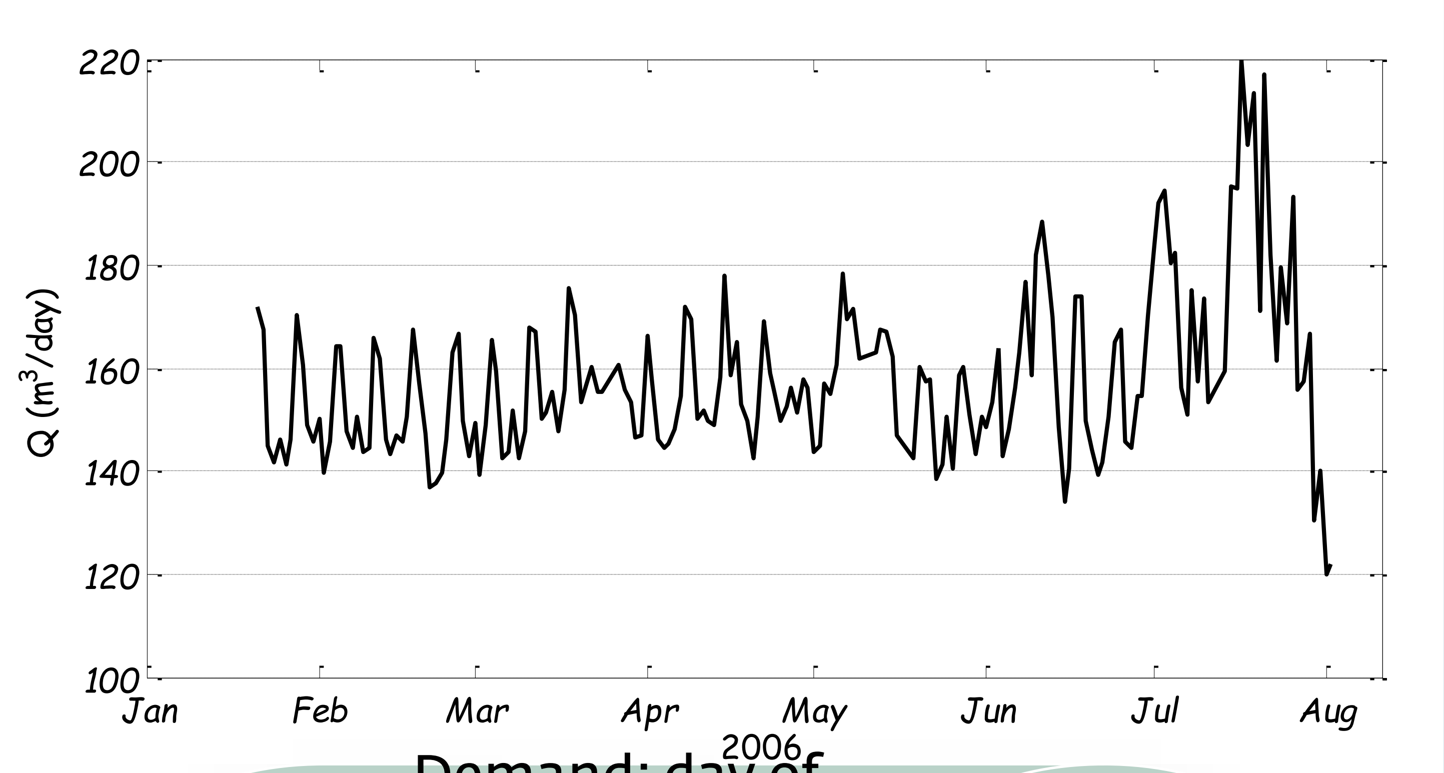
Different spatial and temporal scales

Security of supply, amounts

PRODUCTION STATION

PUMPING STATION DEMAND PATTERNS

Time step: 1 day

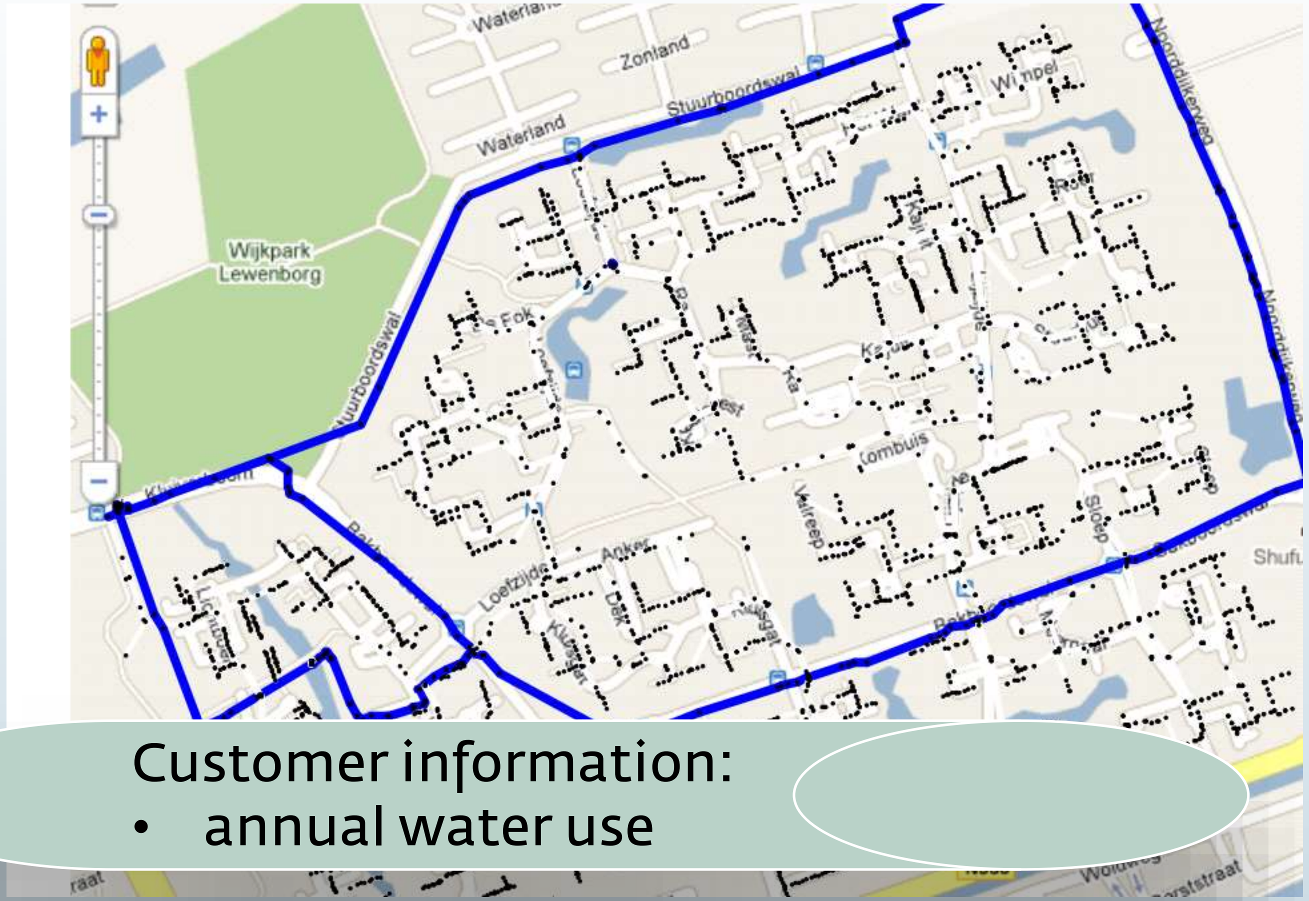


Demand: day of week, temperature and rain, special events

Different spatial and temporal scales

Security of supply, pressures

SKELETONIZED MODEL – ONLY TRANSPORT MAINS

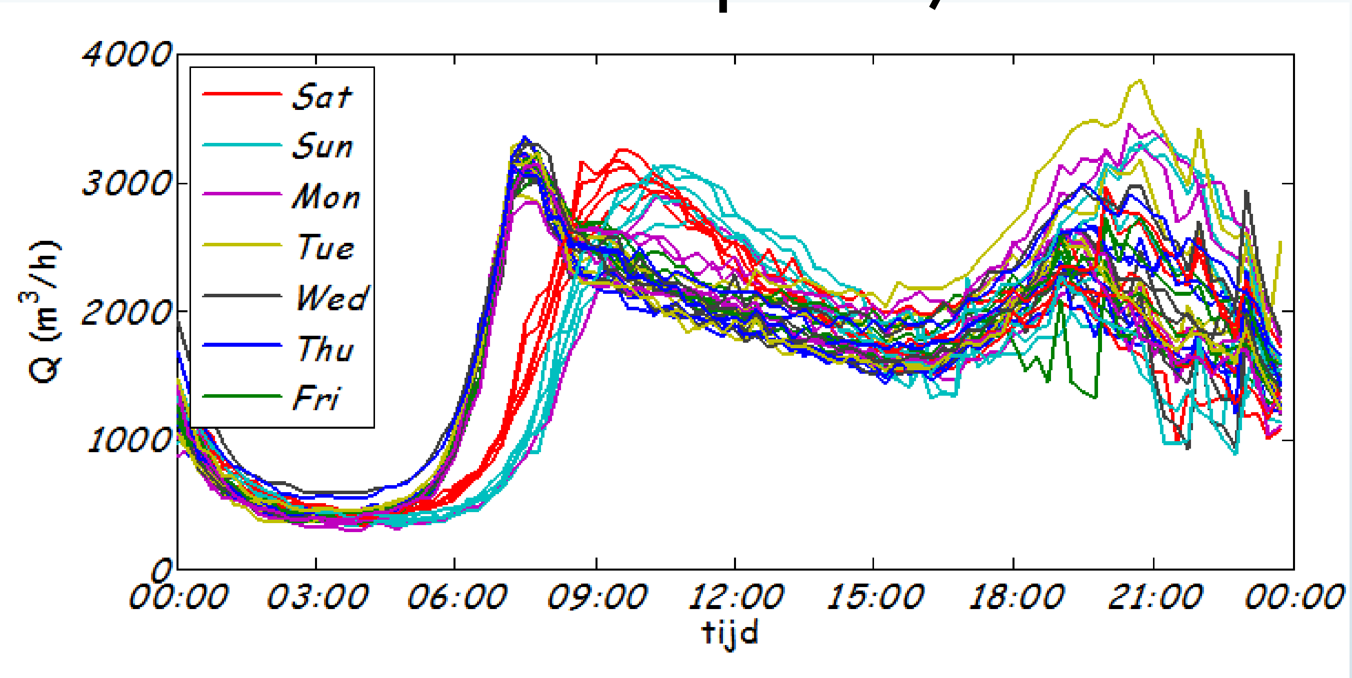


Customer information:

- annual water use

PUMPING STATION DEMAND PATTERNS

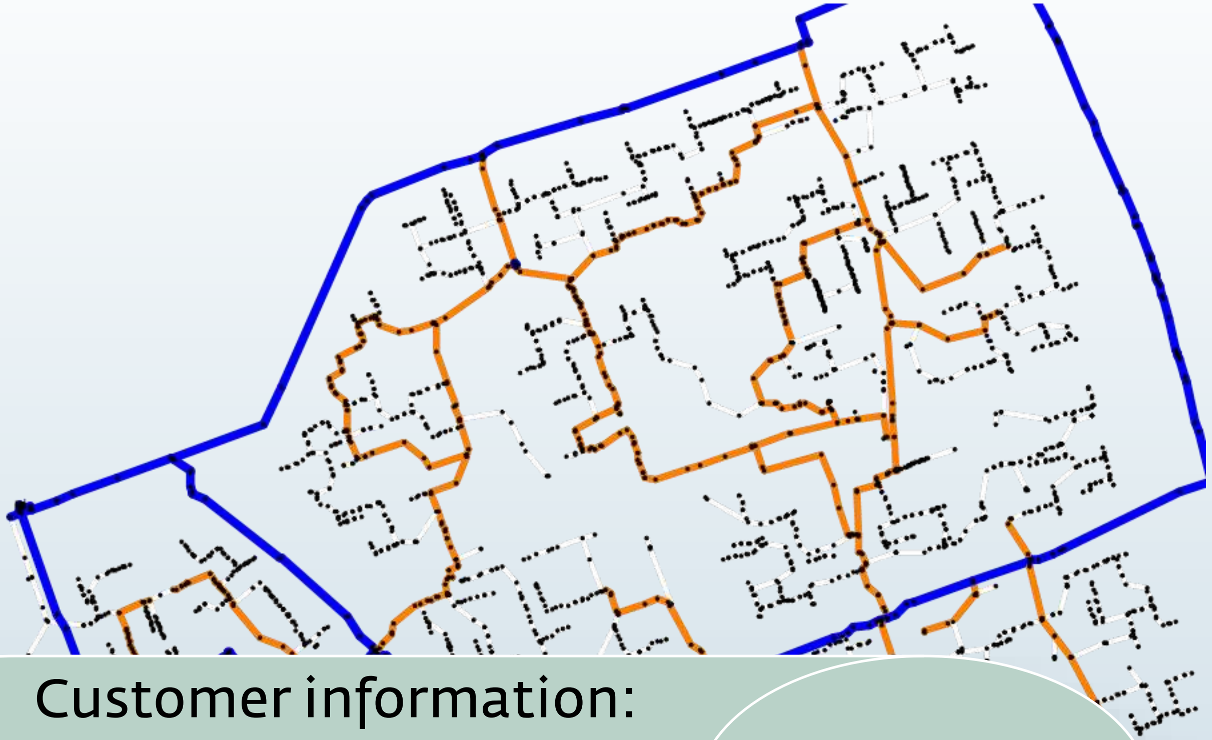
Time step: 1 h / 15 min



Different spatial and temporal scales

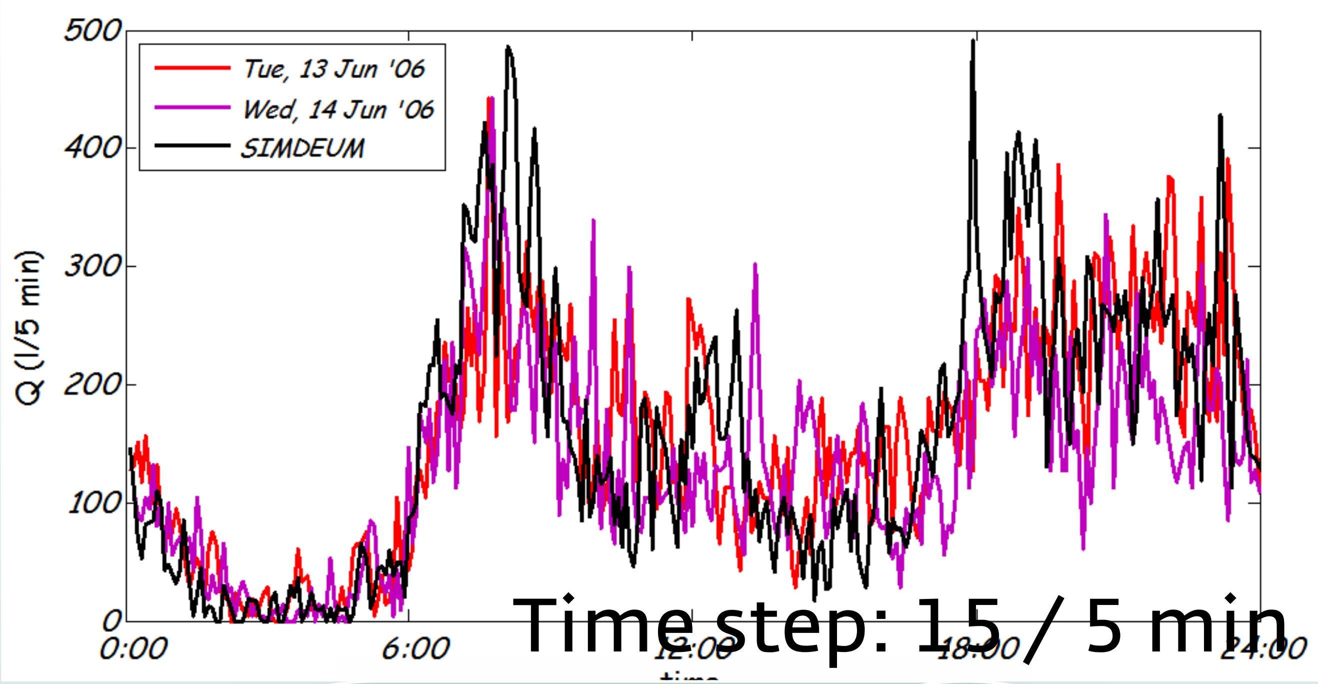
Continuity of supply

SKELETONIZED MODEL – TRANSPORT AND LARGE DISTRIBUTION MAINS



Customer information:
- annual water use
- user type: residential / office /hotel etc.

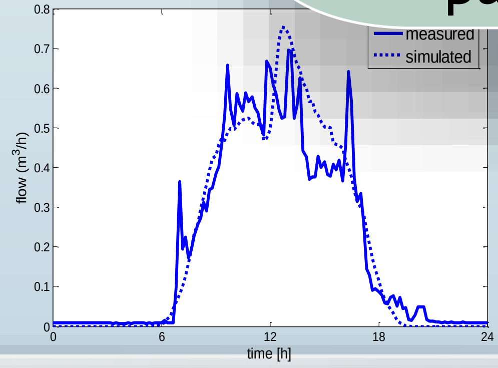
RESIDENTIAL DEMAND PATTERNS

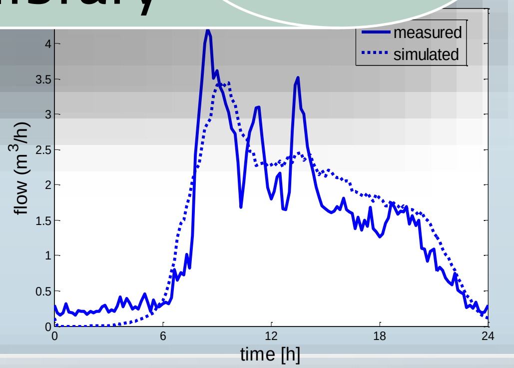


Time step: 15 / 5 min

OFFICE DEM… …TTERNS

Water demand pattern library

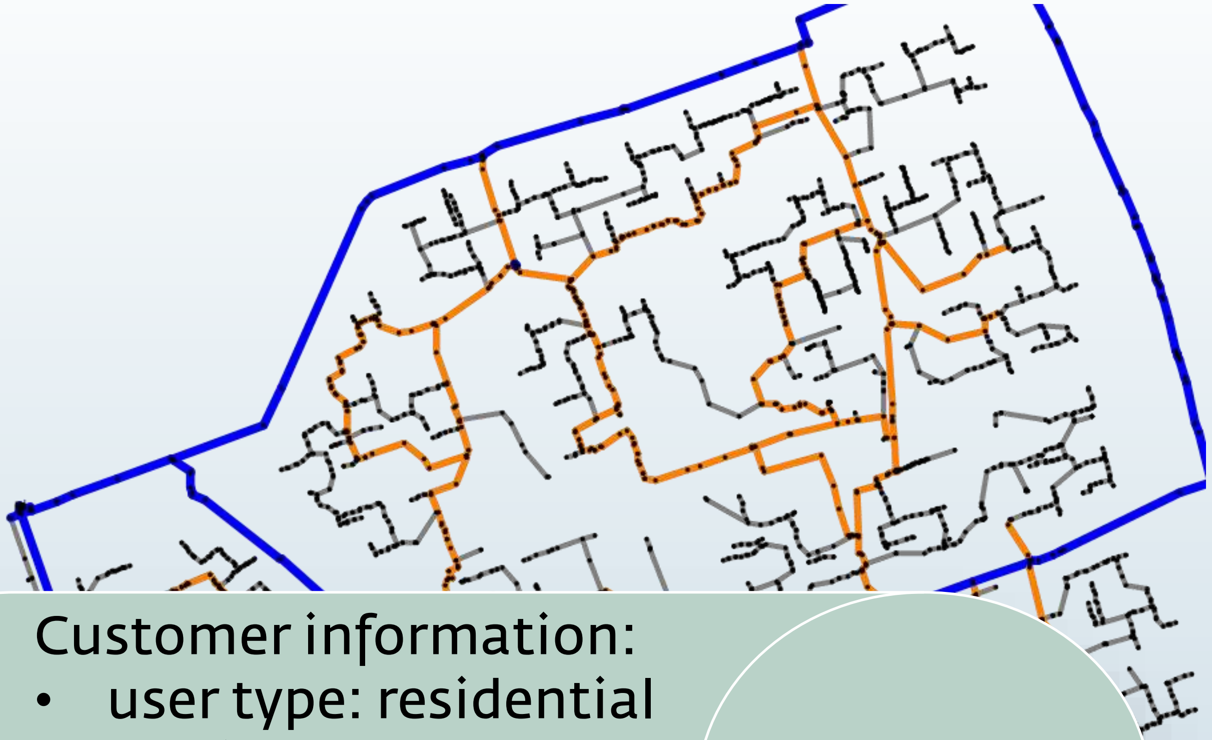




Different spatial and temporal scales

Water quality: water age, turbidity, regrowth, sensors

ALL PIPES MODEL

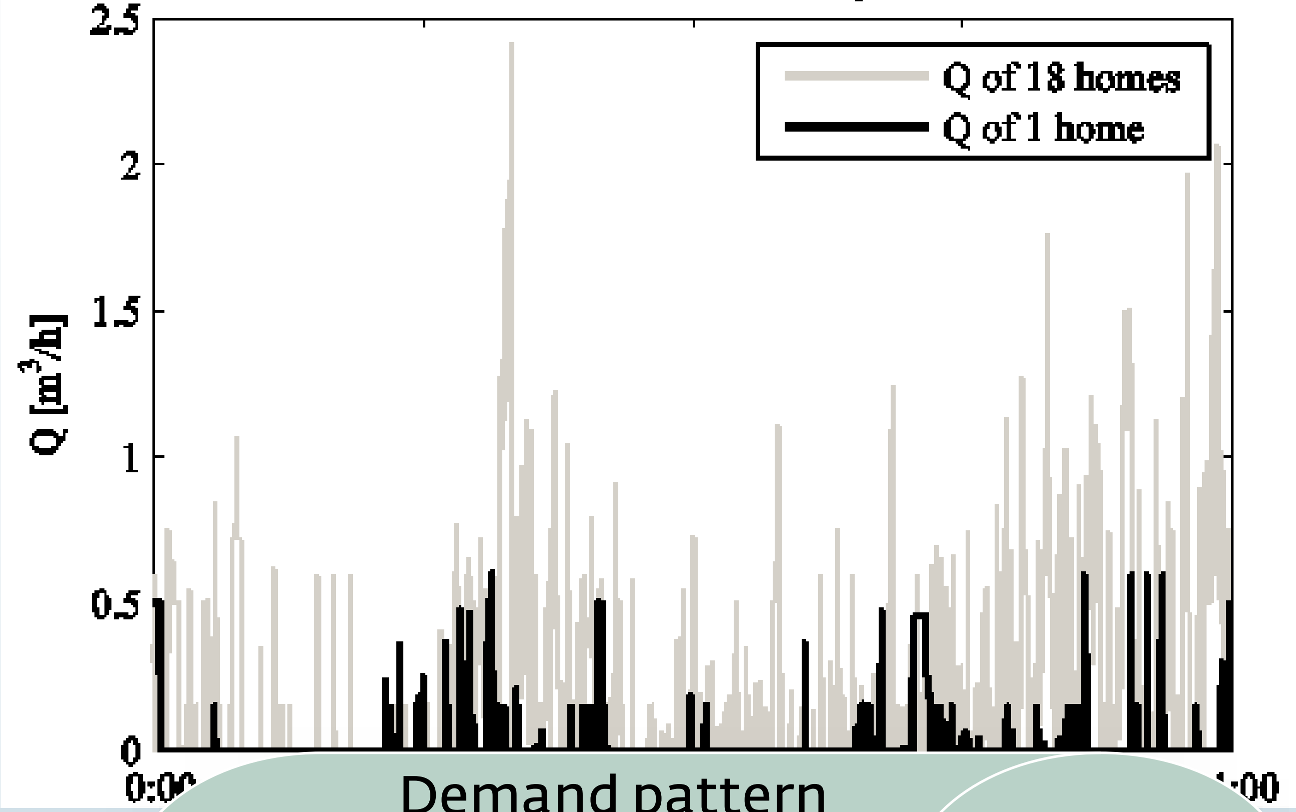


Customer information:

- user type: residential / office /hotel etc.
- # of people / beds
- Water using behaviour

INDIVIDUAL DEMAND PATTERNS

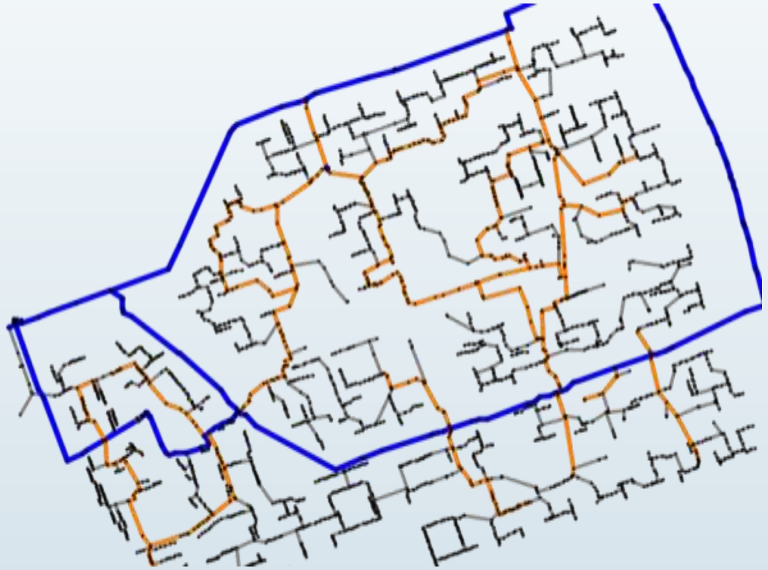
Time step: 1 min / 10 s



Demand pattern generator + automatic demand allocation

Step 1: automatic model generation

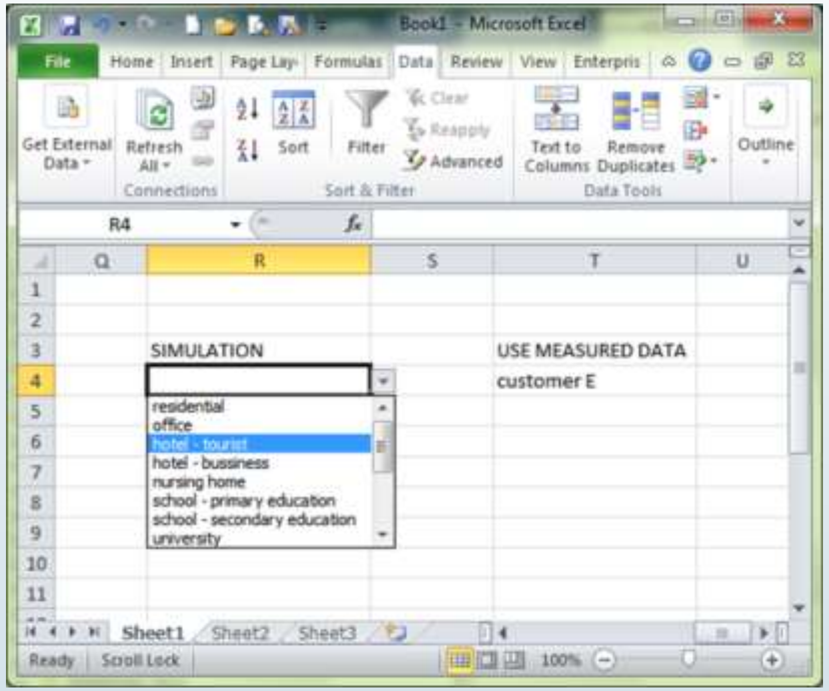
ALL PIPES FROM GIS DATABASE OF MAINS



DEMAND ALLOCATION

schools

DEMAND PATTERNS

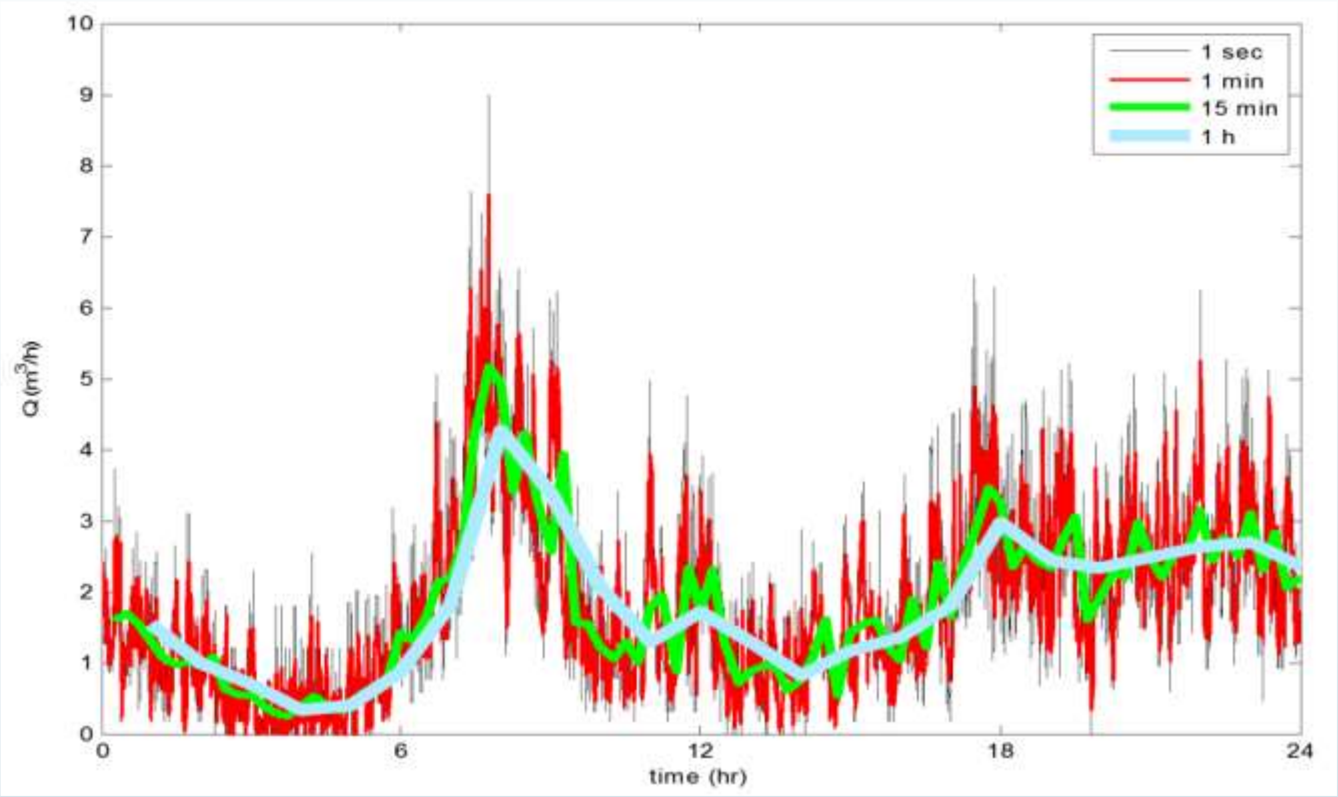


Step 2: zooming into appropriate level

"google earth" – taking into account all scaling laws

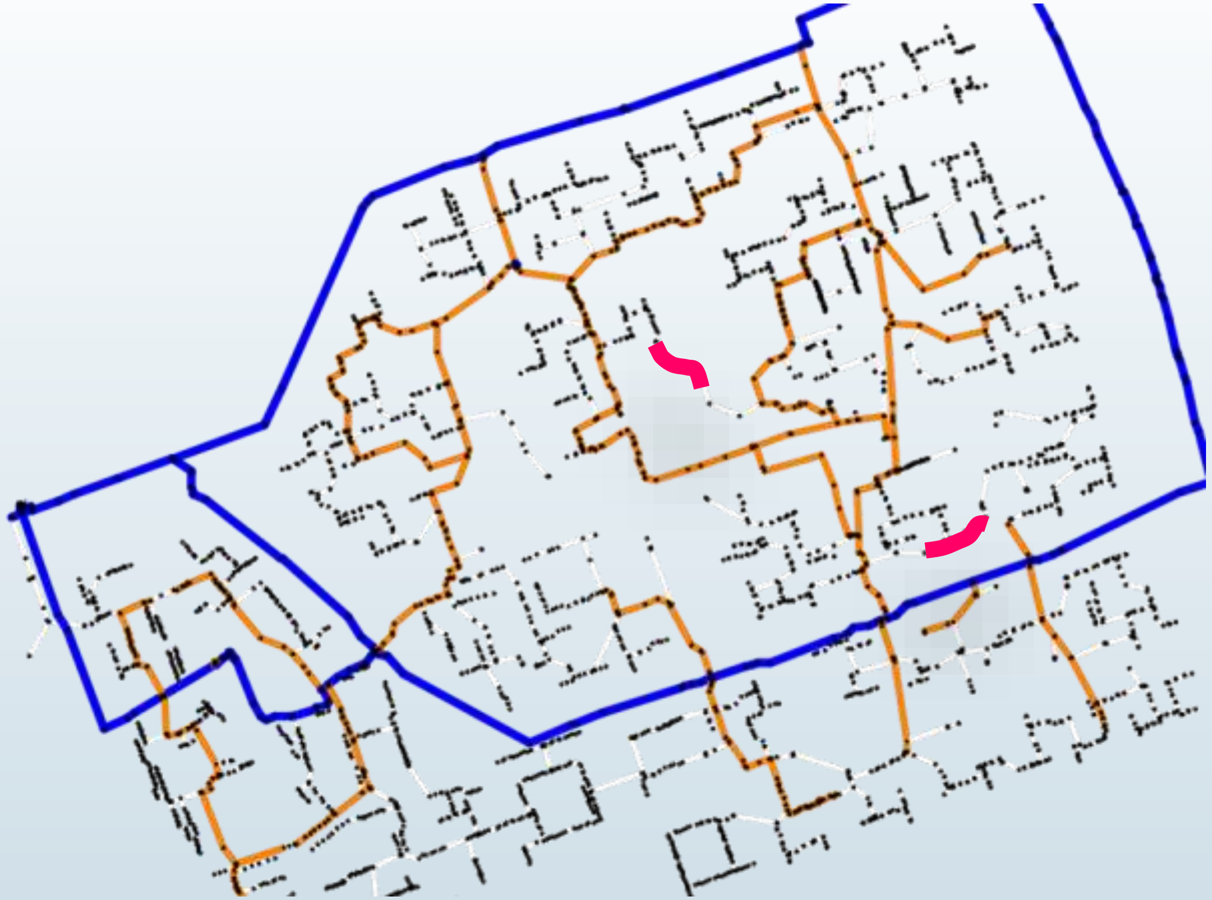
ADJUST SPATIAL SCALE

ADJUST DEMAND AND TEMPORAL SCALE

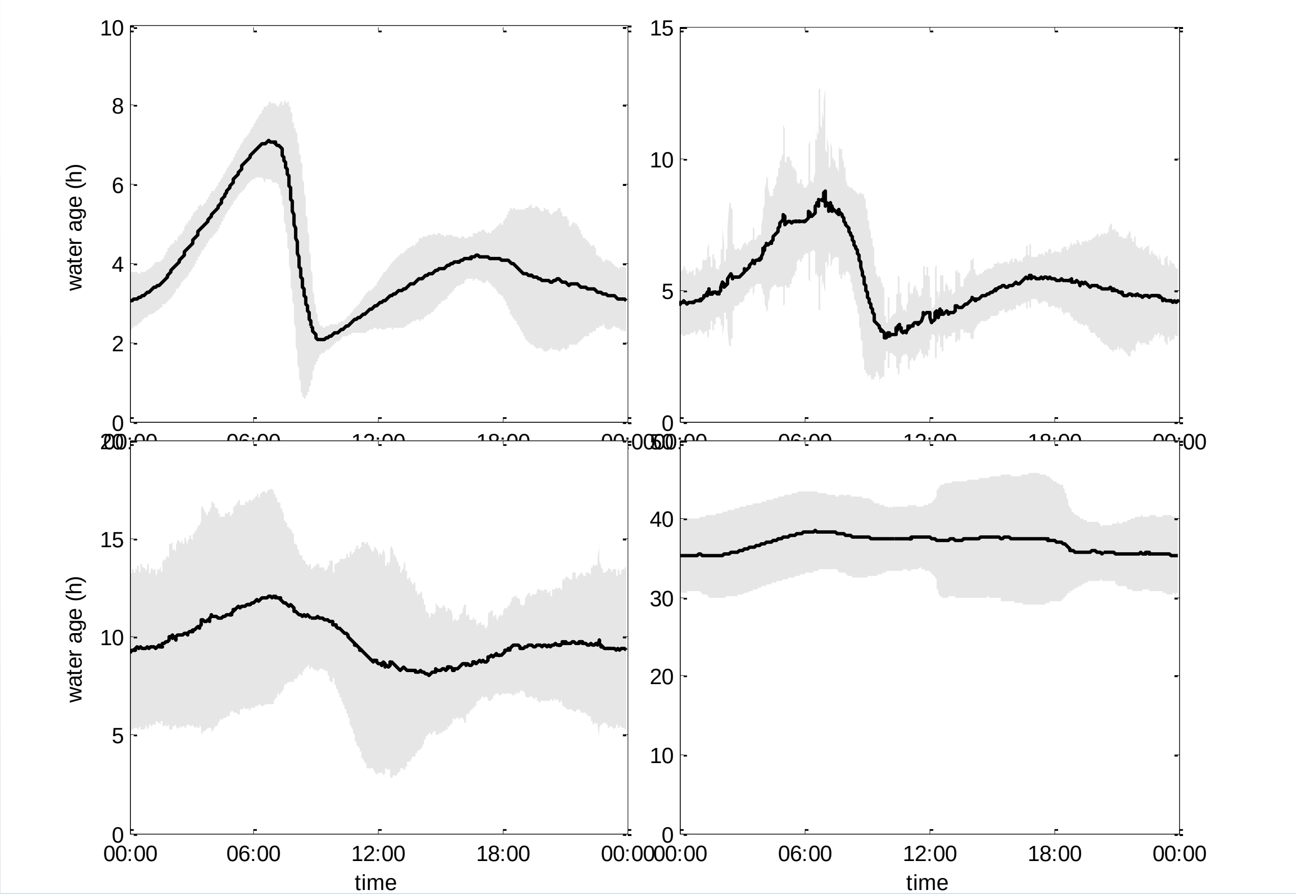


Step 3: analysis of stochastic results

PROBABILITY OF TOO LONG RESIDENCE TIMES



AVERAGE RESIDENCE TIME AND VARIATION



And of course …

easy to use

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Water demand modelling: The key to understanding the water cycle

Mirjam Blokker