CT4491

Lecture. Design Storms and hydrological models for urban drainage systems

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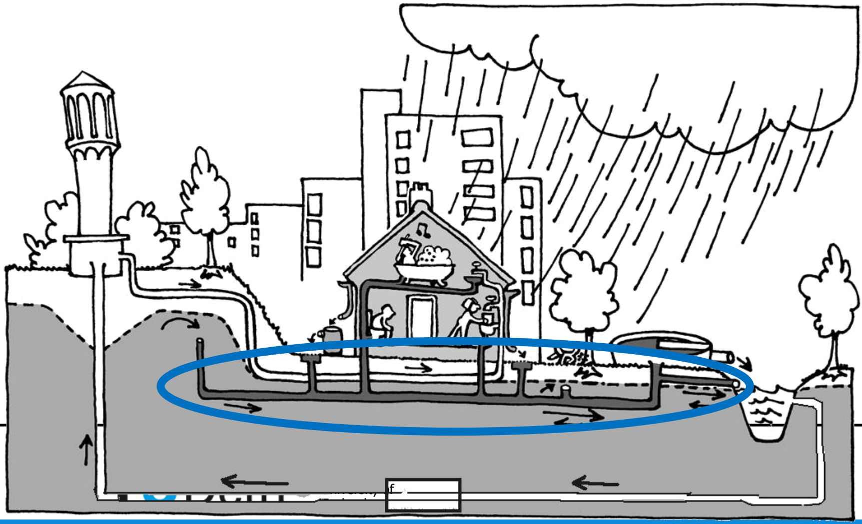
8-10-2013



Source: news.bbc.co.uk

Source: www.nu.nl

Use of rainfall data in urban drainage system design and analysis

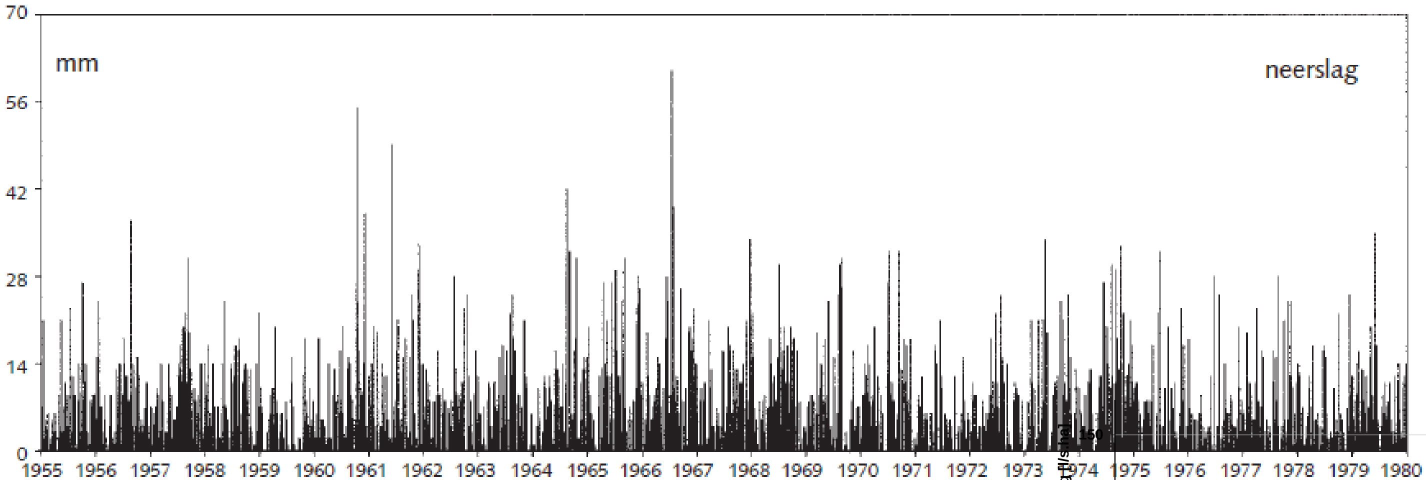
Two approaches:

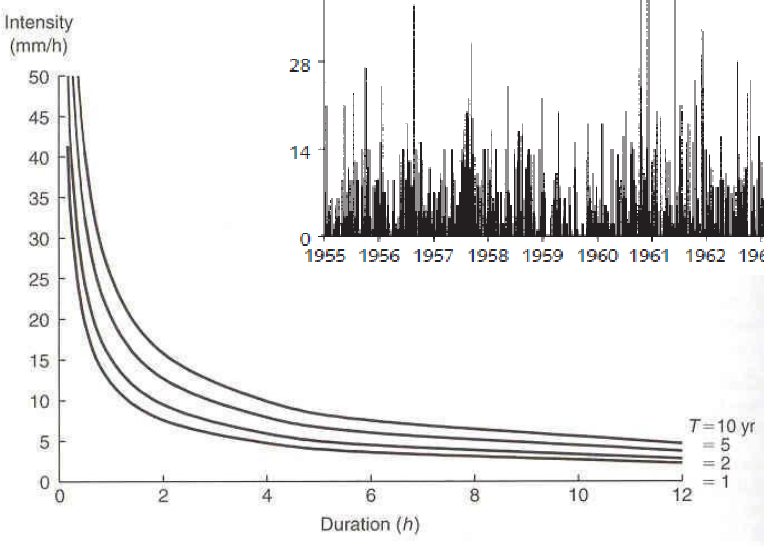
- Stationary/steady state analysis:
  constant rainfall intensity, stationary flow

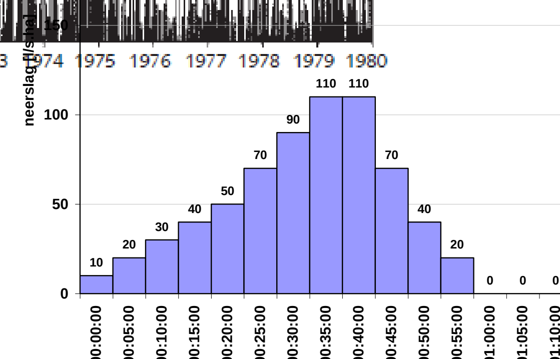
- Dynamic analysis:
  variable rainfall intensity, non-stationary flow

Rainfall data in urban drainage system design and analysis

How to compose or choose a representative rainfall intensity/event from rainfall time-series?







Rainfall data in urban drainage system design and analysis

- for Design:

  How to choose rainfall characteristics, representative of a pre-defined protection level, over a system's lifetime?

- for Analysis:

  How to find rainfall intensities characteristic of the conditions we want to check performance for?

Rainfall data in storm water system design and analysis

Stationary conditions: representative of real-life conditions?

NO

Why use stationary conditions and IDF-curves?

Rainfall data in storm water system design and analysis

Stationary conditions: representative of real-life conditions?

NO

Why use stationary conditions and IDF-curves?

- Quickscan required dimensions new system
- Quickscan capacity limits of existing system
- Manual design: where there is no computer (some areas of the world; 19th and 20th century, up to ±1990)

Rainfall data in storm water system design and analysis

Stationary conditions: representative of real-life conditions?

NO

Why use stationary conditions and IDF-curves?

- Where there is a lack of data to build a proper model (many areas worldwide, incl Europe!)

Dynamic rainfall intensity for stormwater design, design storms

Rainfall data in urban drainage design and analysis

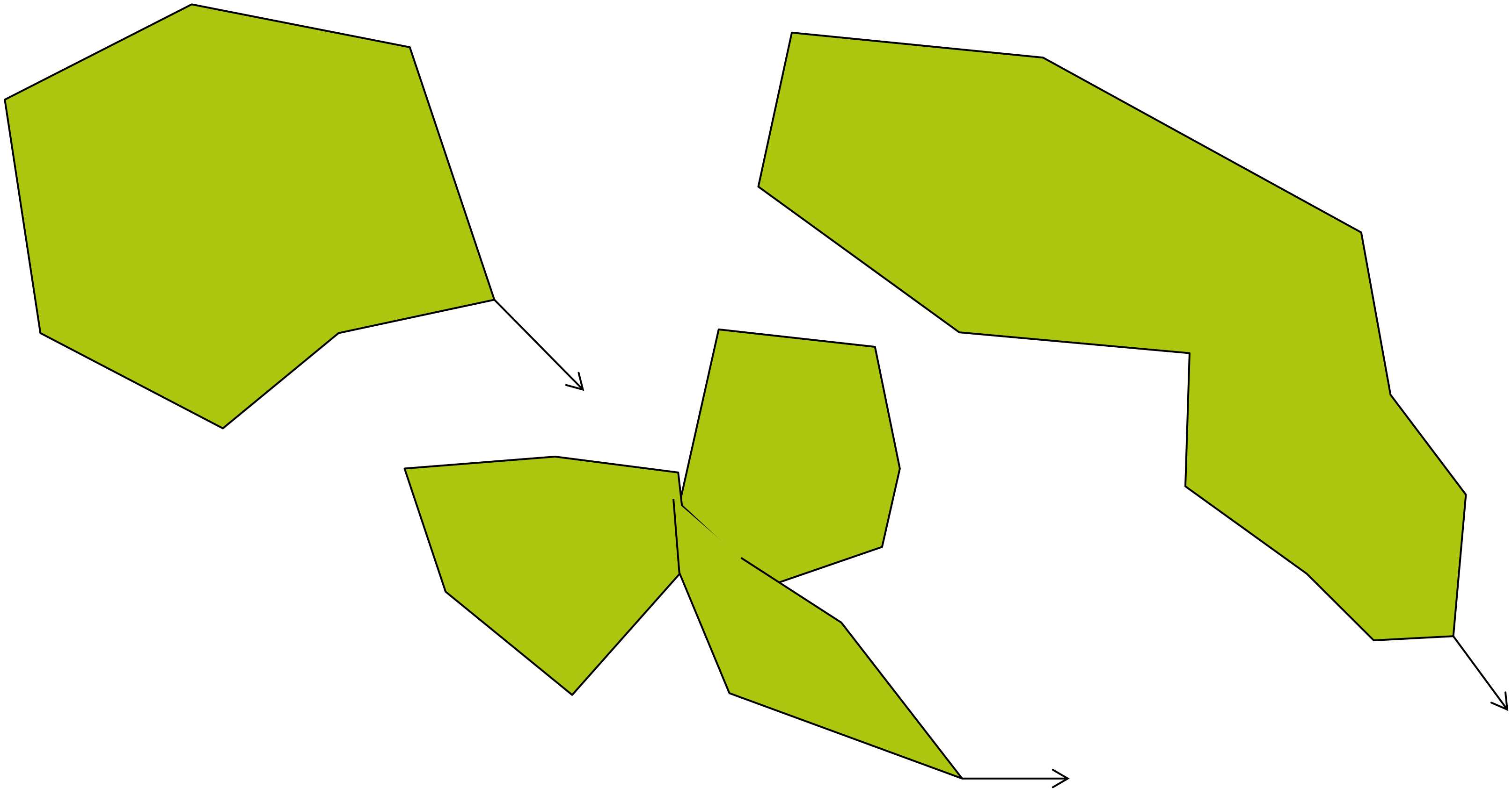
- If dynamic calculation is reasonable: use dynamic rainfall conditions

What rainfall characteristics to choose?

- Maximum intensity of a rain event (mm/h)
- Total volume of a rain event (mm)
- Duration of a rain event (h)
- Variation in intensities, high versus low

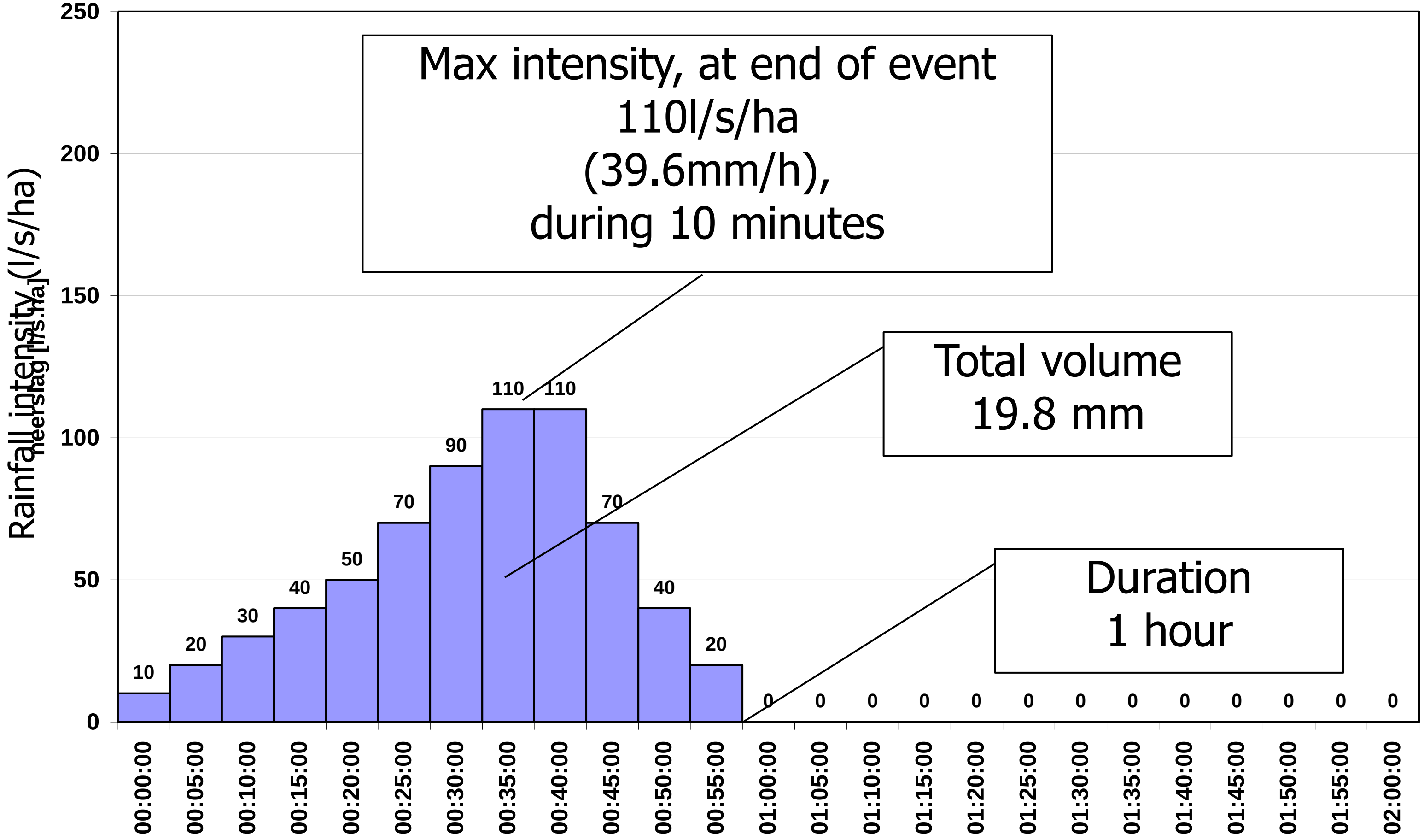
- What is critical for the system we want to design/analyse?

- What is critical for the system we want to design/analyse?

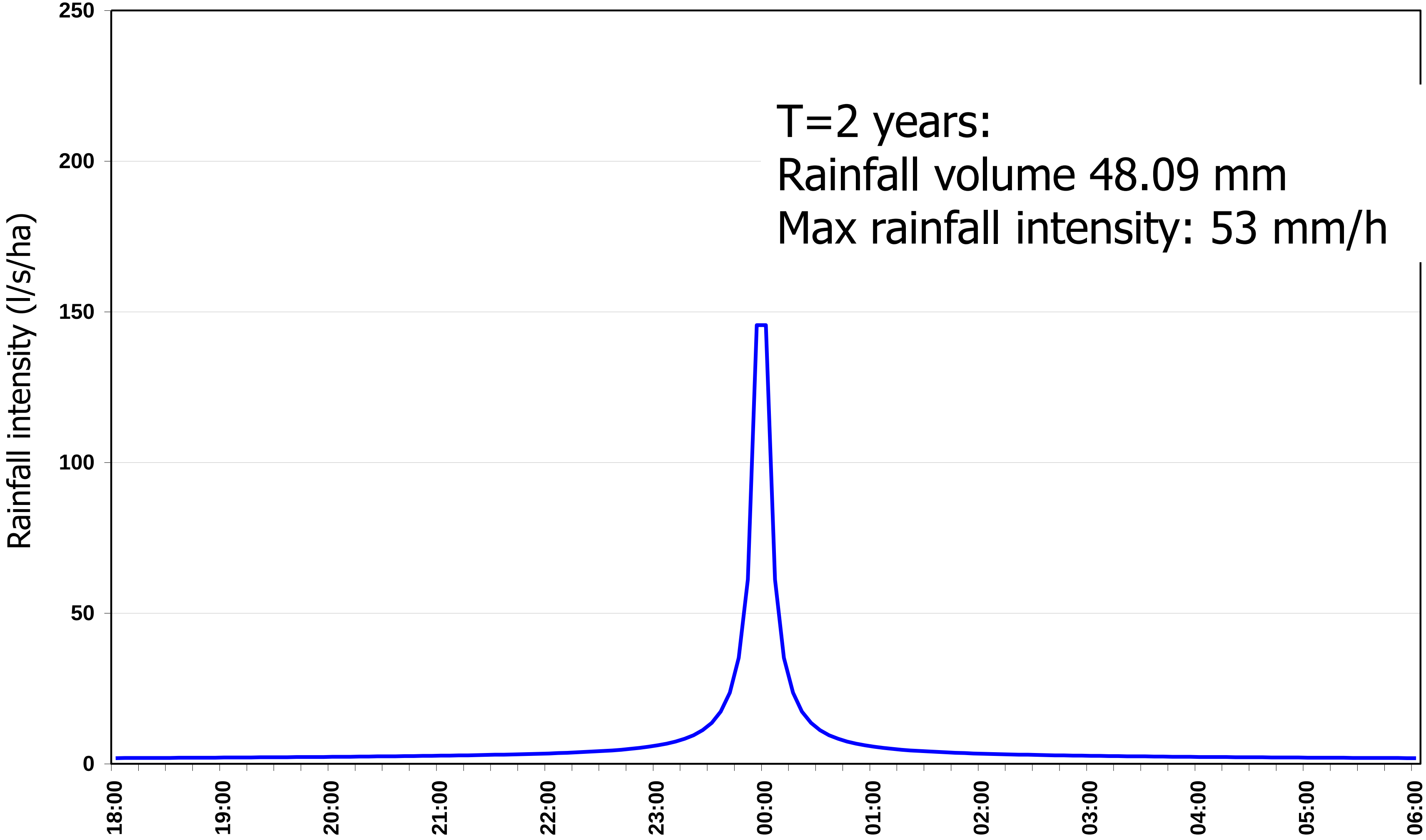


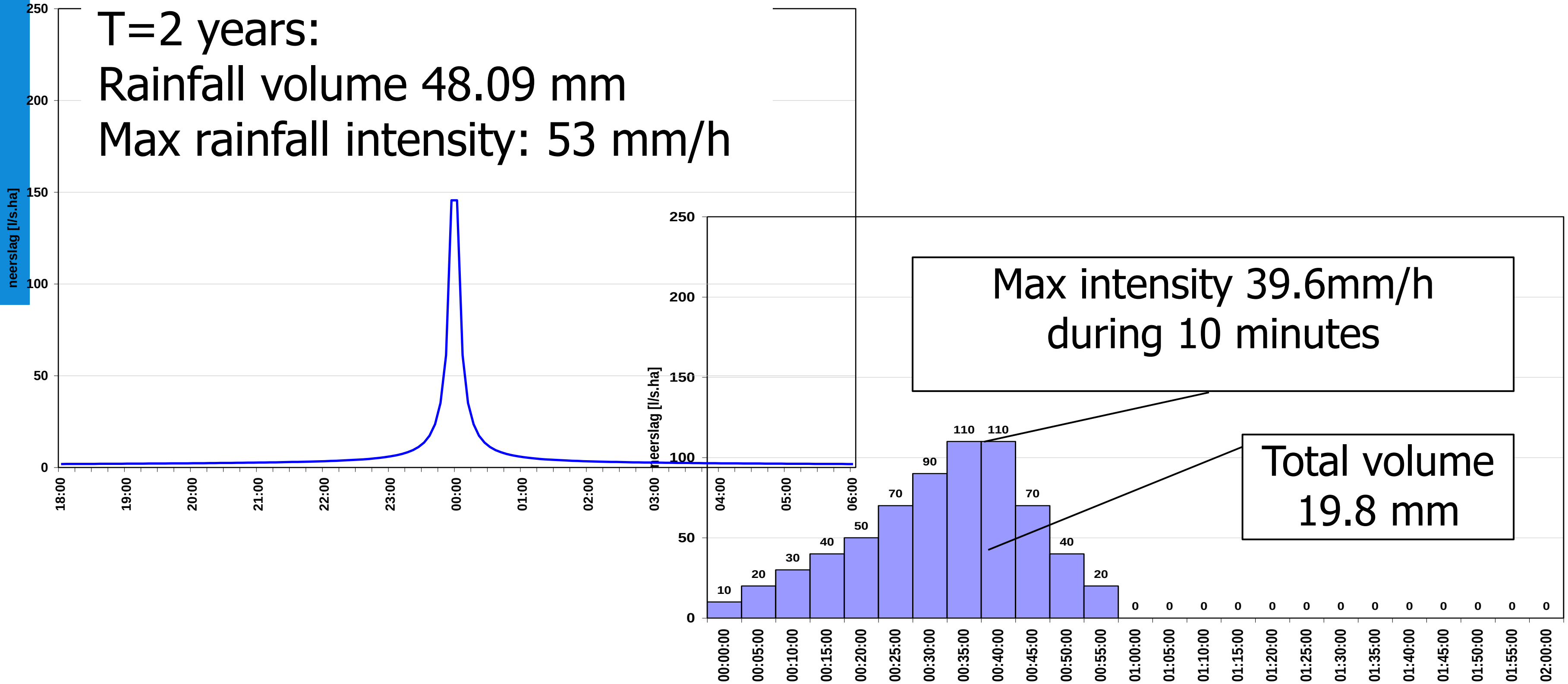
- Depends on characteristics of the catchment: dimensions, imperviousness, slope

Example synthetic standard design storm T=2 years (NL: “Bui 08”)



Synthetic storm T=2 jaar (e.g Belgium)





- Can you explain why different design storms have been chosen for BE and NL?
- What do you expect to find when you apply the BE T=2yr design storm to a system designed according to NL T=2yr storm ?

Use of rainfall data in urban drainage design

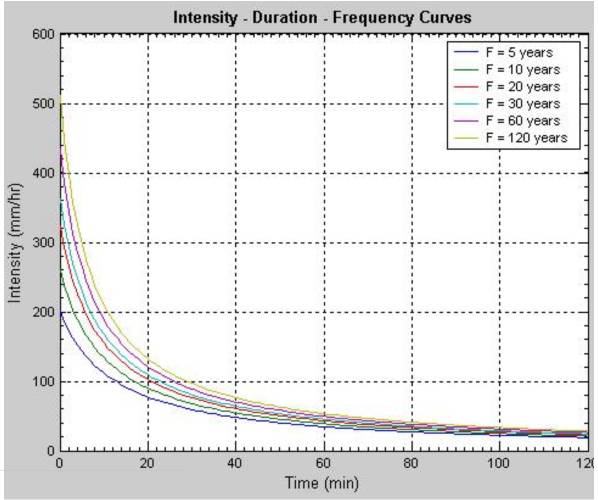
Multiple event:

- Historical: rainfall measurements
  e.g. in the Netherlands: time series of KNMI De Bilt,
  15 minute time step:
  - 10 year series: 1955-1964
  - 25 year series: 1955-1979

→ Mainly used for analysis of annual pollution from cso's
→ **Because (why not for flooding analysis?):**

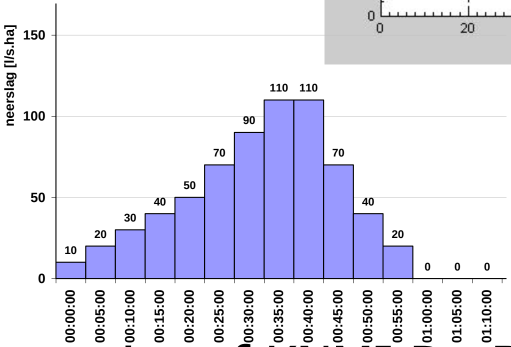
- Synthetic rainfall series

Rainfall input for urban drainage design



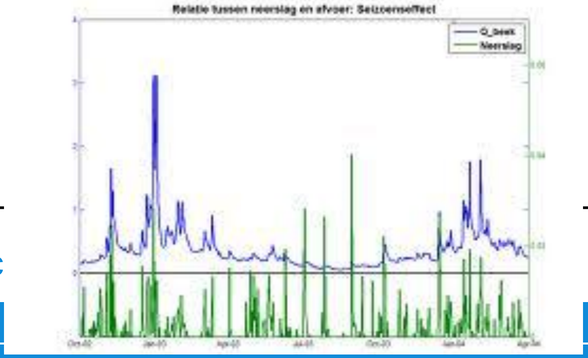
To summarise:

- Stationary design
  - IDF curves, fixed design rainfall intensity



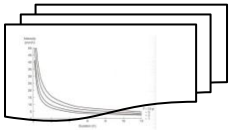
- Dynamic design, single event:
  - Design storm

- Multiple event/rainfall series
  - Historical series
    e.g. in the Netherlands: time series of KNMI De Bilt, 10 or 25 yrs
  - Synthetic rainfall series



Robust method stationary modelling

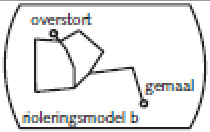
IDF curves



Rainfall runoff modelling

Rational method

Branched networks (few loops)



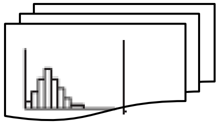
Stationary hydraulic calculations

gb1/ kn1 (-)	gb2/ kn2 (-)	begin-tijd (min)	hoeveel-heid m³	(%)	duur (min) netto	bruto
02013	-	19	298	11	27	27
04003	-	27	9	0	9	9
06004	-	22	123	5	49	49

Water levels in nodes

Storm event dynamic modelling

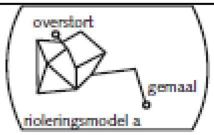
Design storms



Rainfall runoff modelling

Hydrodynamic model calculations

Detailed branched and looped networks

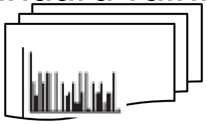


Dynamic hydraulic calculations

Q-t diagram per node per storm event

Rainfall series dynamic modelling

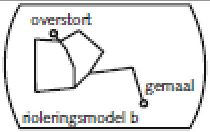
Standard rainfall series



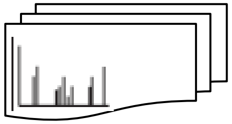
Rainfall runoff modelling

Hydrodynamic model calculations

Simplified branched and looped networks



Dynamic hydraulic calculations



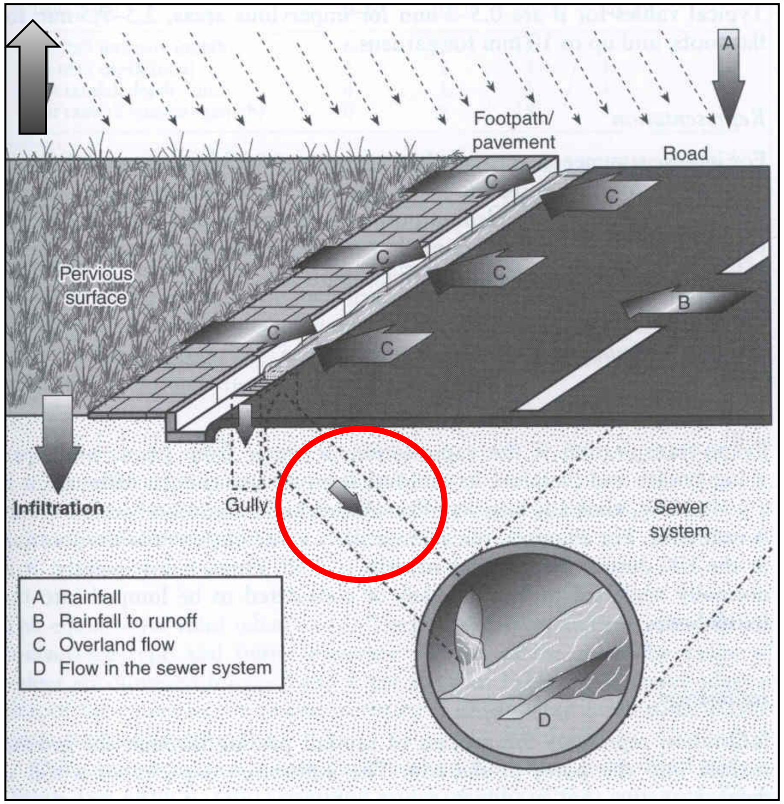
Q-t diagram per node for series of storm events

Rainfall-runoff processes, urban hydrology

Transformation of rainfall into runoff: Urban hydrology

Essentially, 4 processes:

- Evaporation ⇑
- Depression storage ⇔
- Infiltration ⇓
- Overland flow ⇒

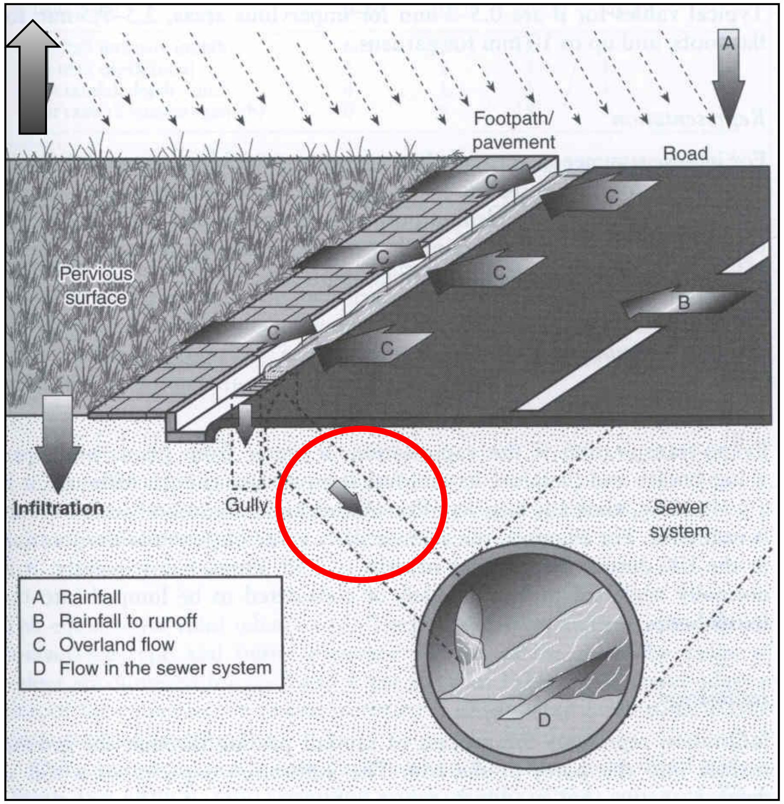


Transformation of rainfall into runoff: Urban hydrology

Essentially, 4 processes:

- Evaporation ⇑
- Depression storage ⇔
- Infiltration ⇓
- Overland flow (delay) ⇒

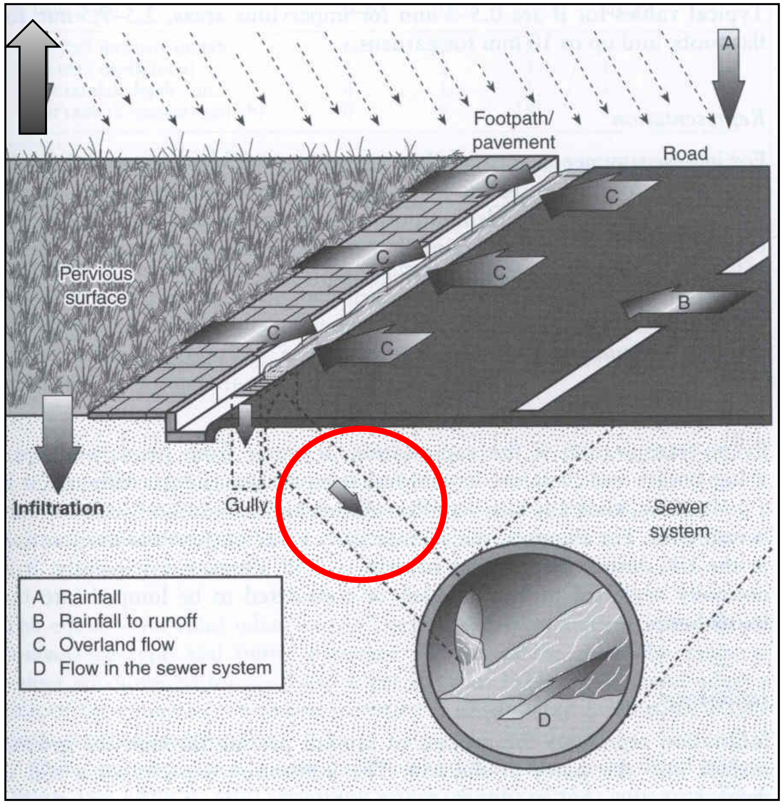
How to model the transformation process?



Transformation of rainfall into runoff: Urban hydrology

How to model the transformation process?

Information needed:
- ?
- ?
- ?
- ?
- ?
- ?
- ?



Transformation of rainfall into runoff

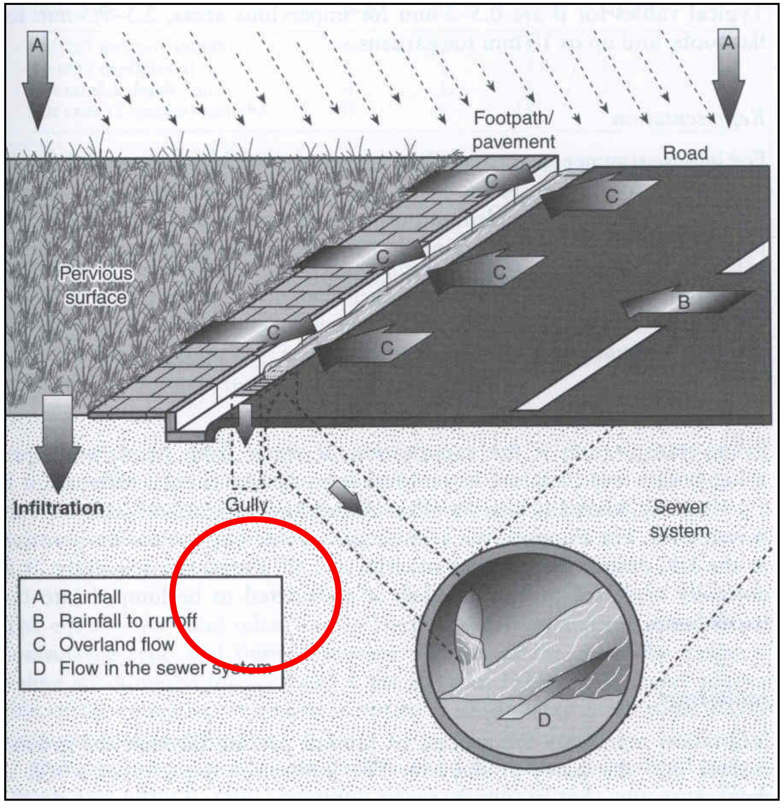
How to model the transformation process?

Information needed:

- Evaporation parameters
- Depression storage parameter
- Infiltration parameters (initial infiltration, max/min infiltration)
- Overland flow time (delay), flow process parameters

Location specific!

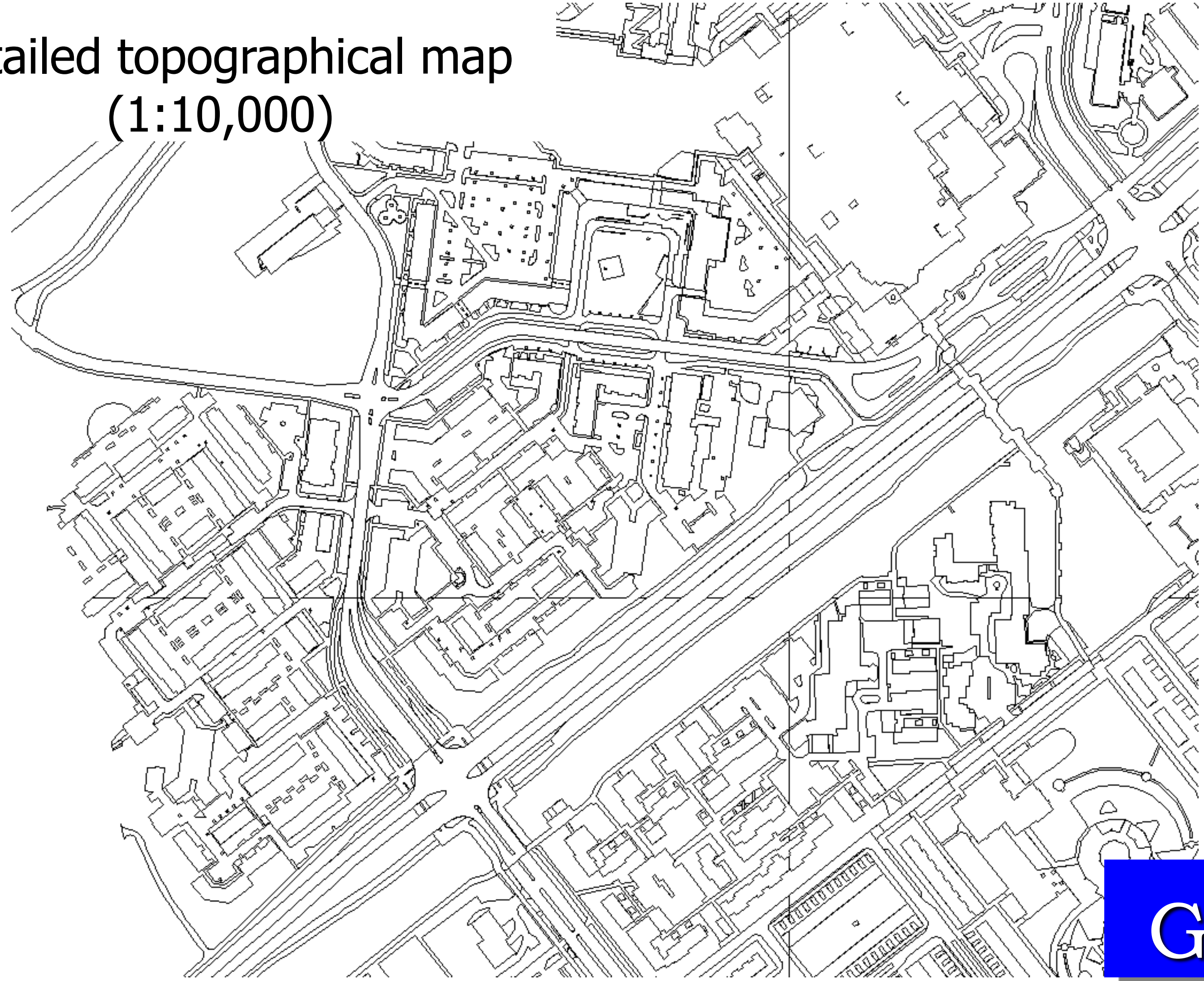
- Urban area characteristics
- Parameters of all urban area types
- Dimensions of urban areas



Aerial photograph of urban catchment

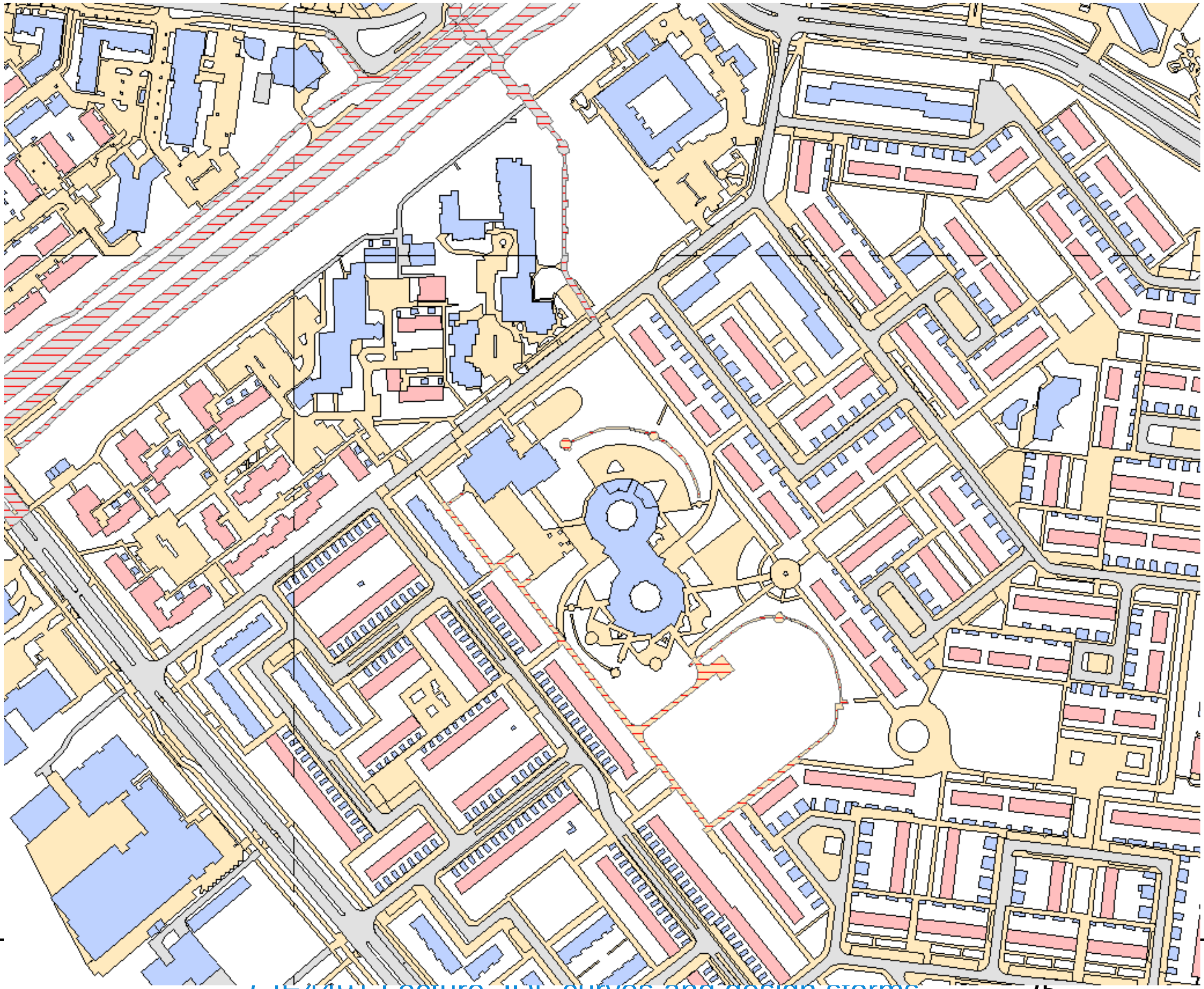
Topography of urban catchment

Detailed topographical map (1:10,000)



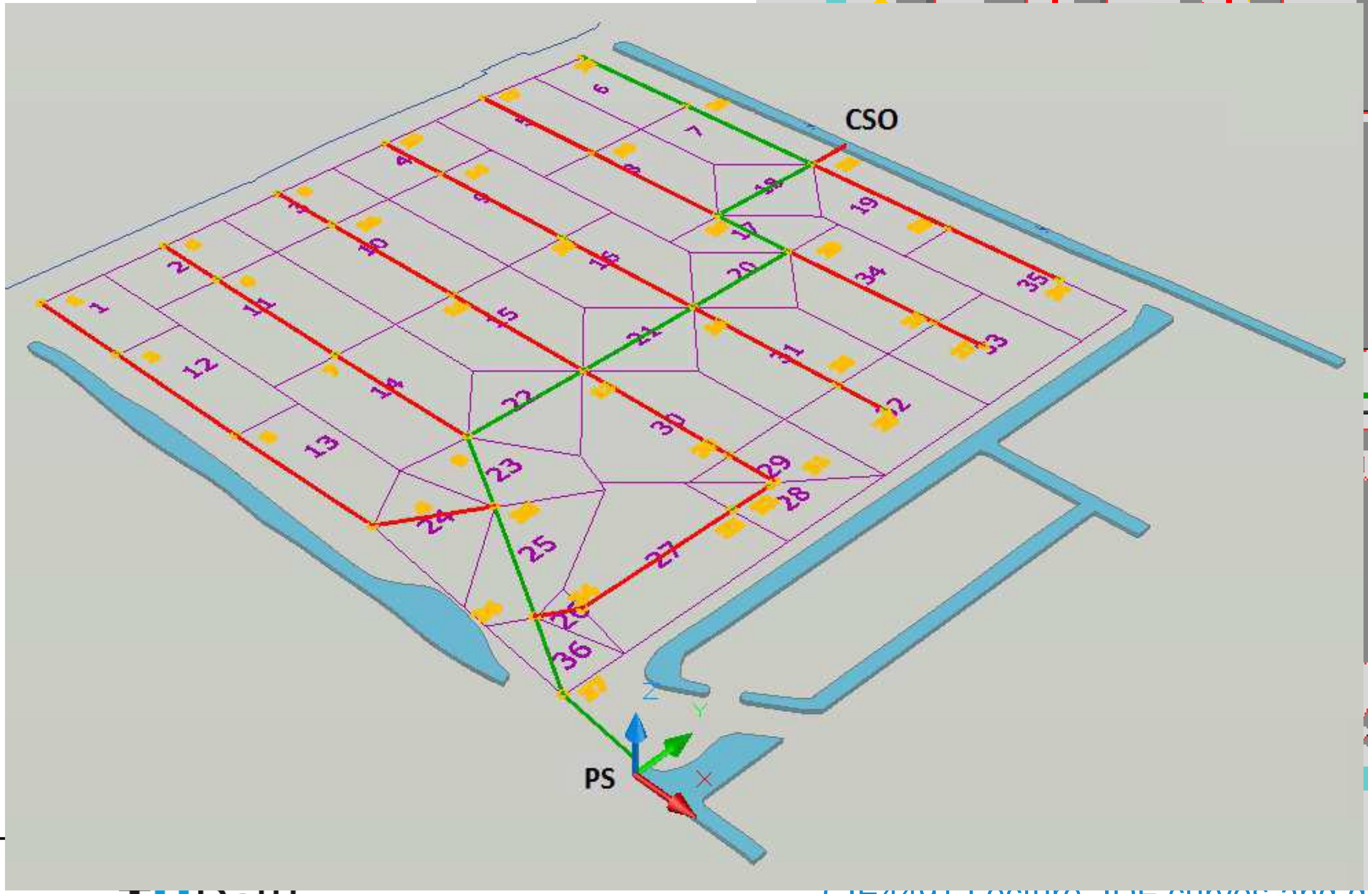
GBKN

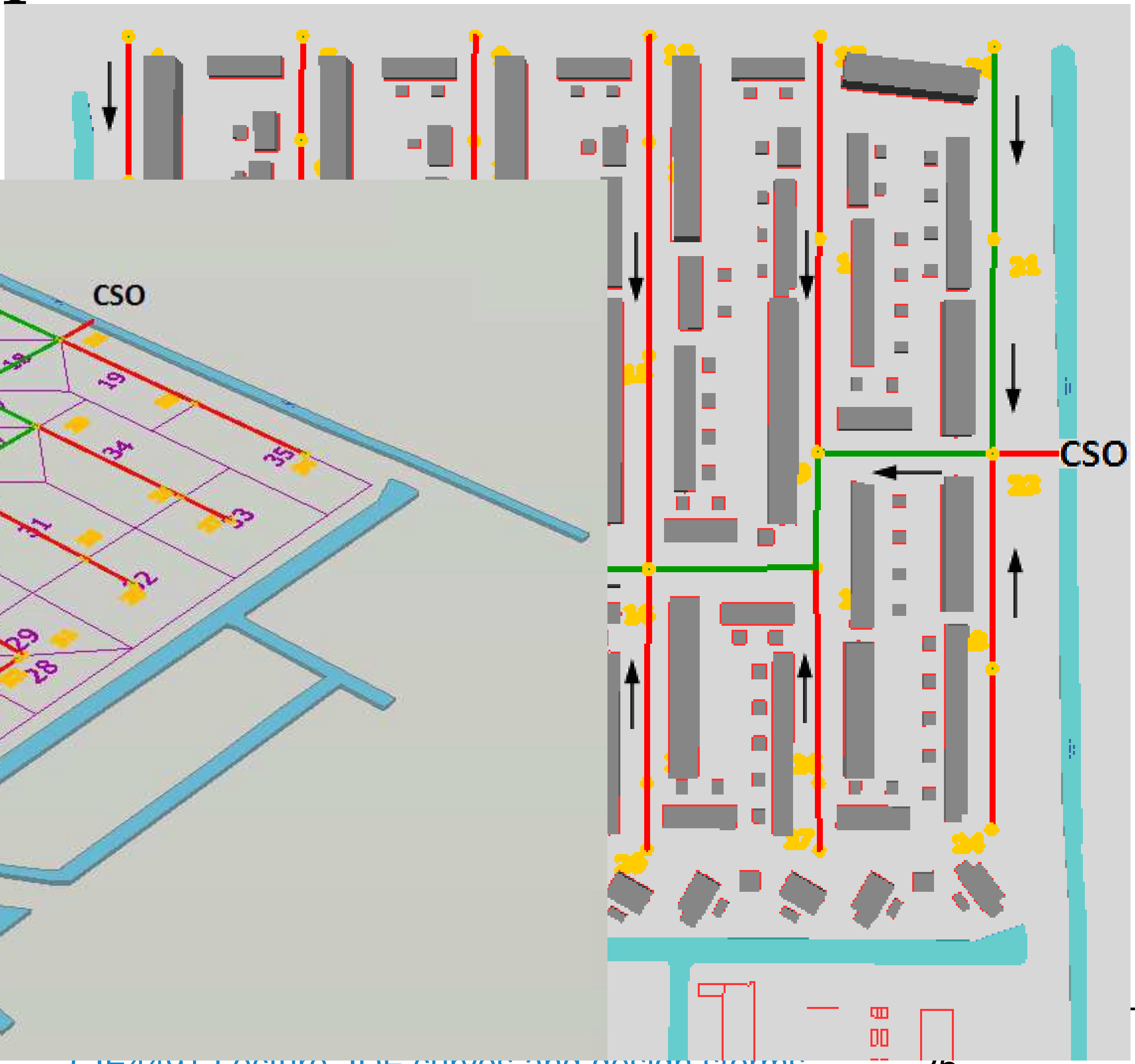
Distinguish different catchment types



Flat roofs
Inclined roofs
Impervious area
Pervious area

Design assignment: average runoff coefficient per subcatchment





Build a hydrological model

For one of the 4 catchment areas:

- Offices in park-like setting
- Residential area, densely built
- Commercial area (shopping centre)
- Residential are, sparsely built

4 available modules for hydrological model:

- Evaporation
- Infiltration
- Depression storage
- Overland flow

- **Decide how many surface types you want to distinguish**
- **For each surface type: choose applicable modules**
- **Indicate importance of each module (+/++)**

Build a hydrological model

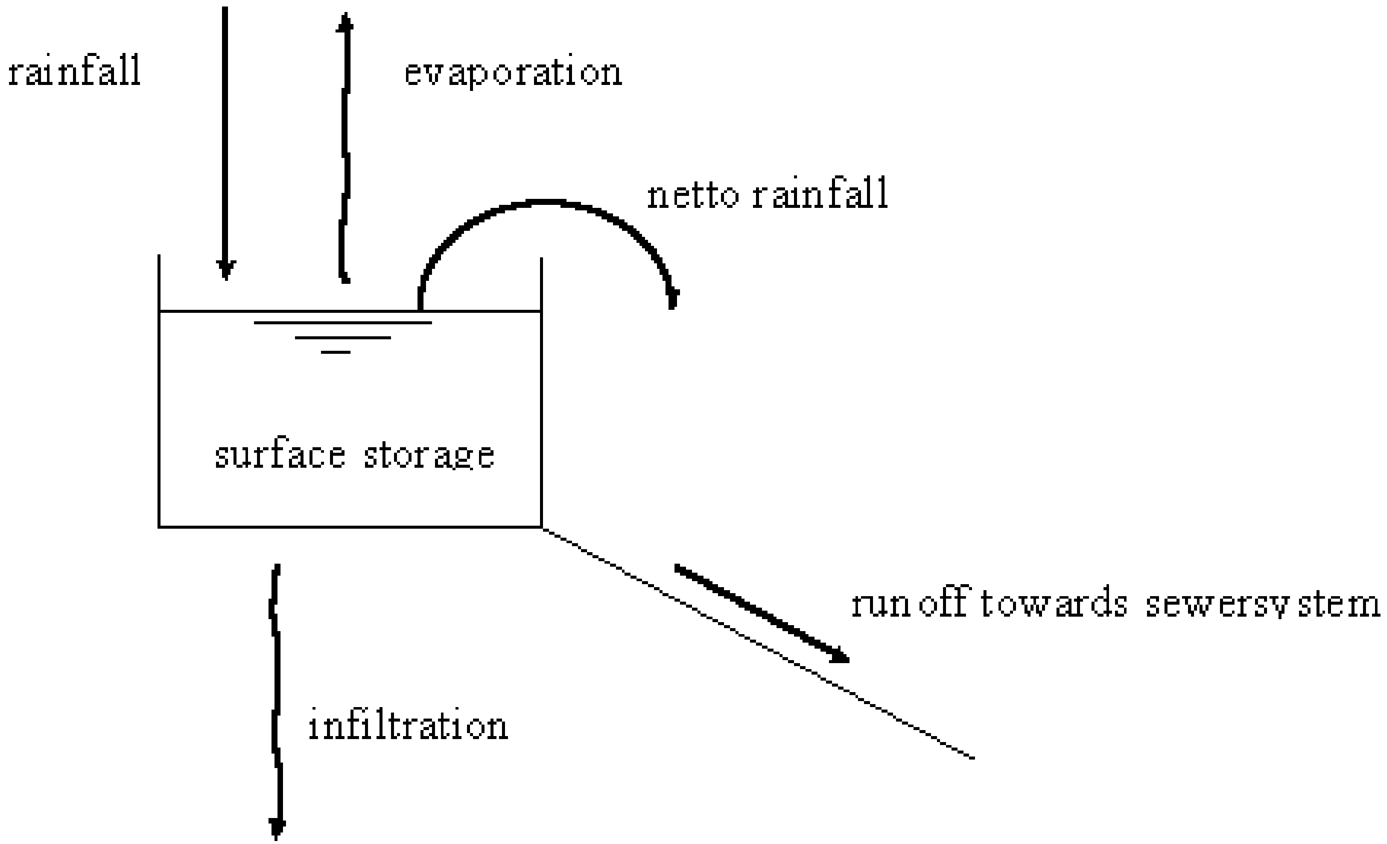
- What processes did you include?
- How many surface types did you distinguish?
- How many model building blocks in total?
- What is most important process?

	Nr of surf types	# Infiltration	#Depression storage	#Overland flow	Total # modules
Office park					
Residential, dense					
Commercial					
Residential, sparse					

Rainfall-runoff processes, representation in hydrodynamic models

Rainfall runoff module

Rainfall runoff model in Sobek: **Sobek-Urban RR**



Rainfall runoff module

Rainfall runoff model in Sobek: **Sobek-Urban RR**

What processes are included?

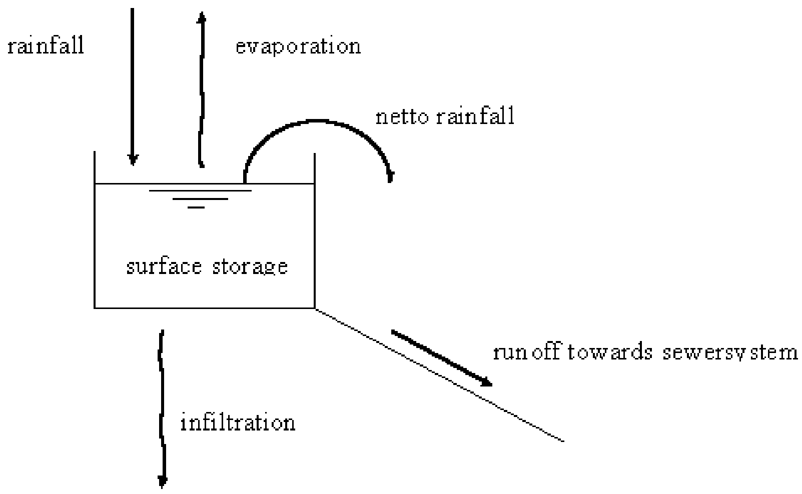
- Depression storage, infiltration, overland flow delay (evap neglected)

How many surface types?

- maximum 12 different surface area types)

How many buildings blocks in total?

- maximum 36 model elements



Rainfall runoff module

Rainfall runoff model in Sobek: **Sobek-Urban RR**

How are processes modeled?

- Depression storage: fixed storage / area type
- Infiltration: Horton – min/max infiltration capacity, decrease/recovery factor
- Delay due to overland flow: "rational method" (delay factor)

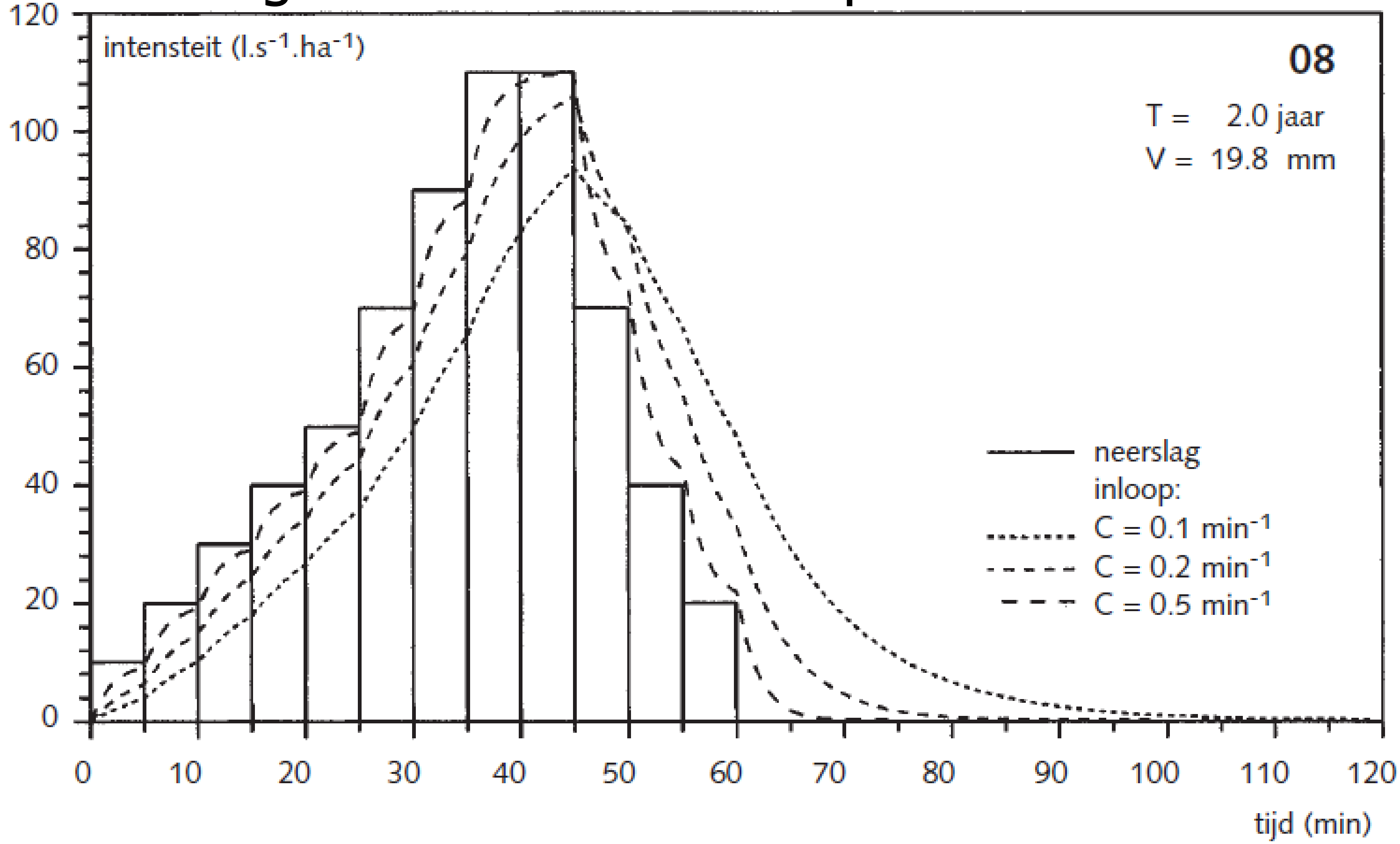
$$q = C * h$$

where: q = inflow into sewer [mm.min-1]
c = runoff factor [min-1]
h = rainfall, dynamic storage on catchment [mm]

Rainfall runoff module

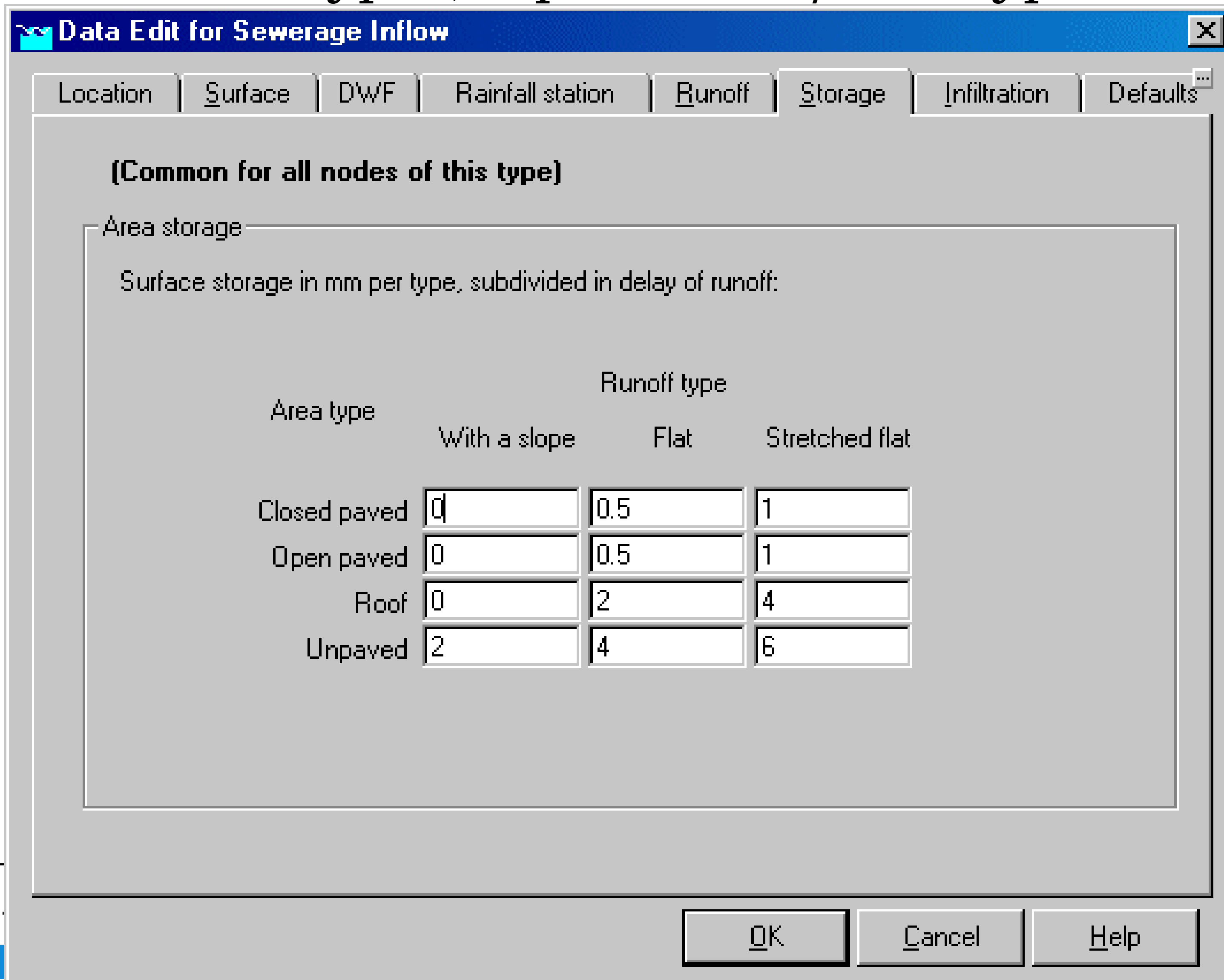
Overland flow – delay factor C (min^{-1})

- part of rainfall that runs off in given time step
- larger C → faster runoff process



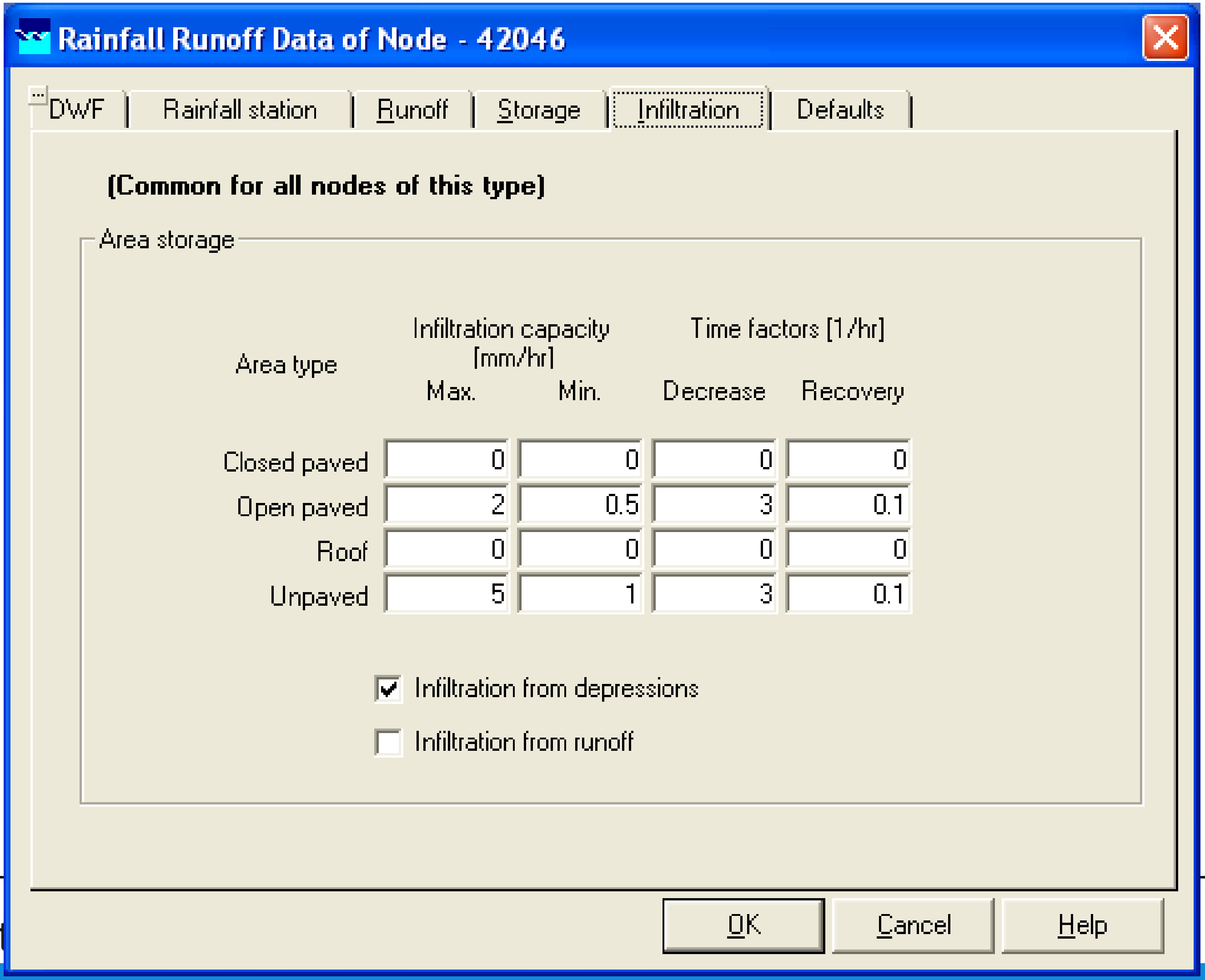
Sobek RR – Area storage (mm)

12 area types, 1 parameter/area type



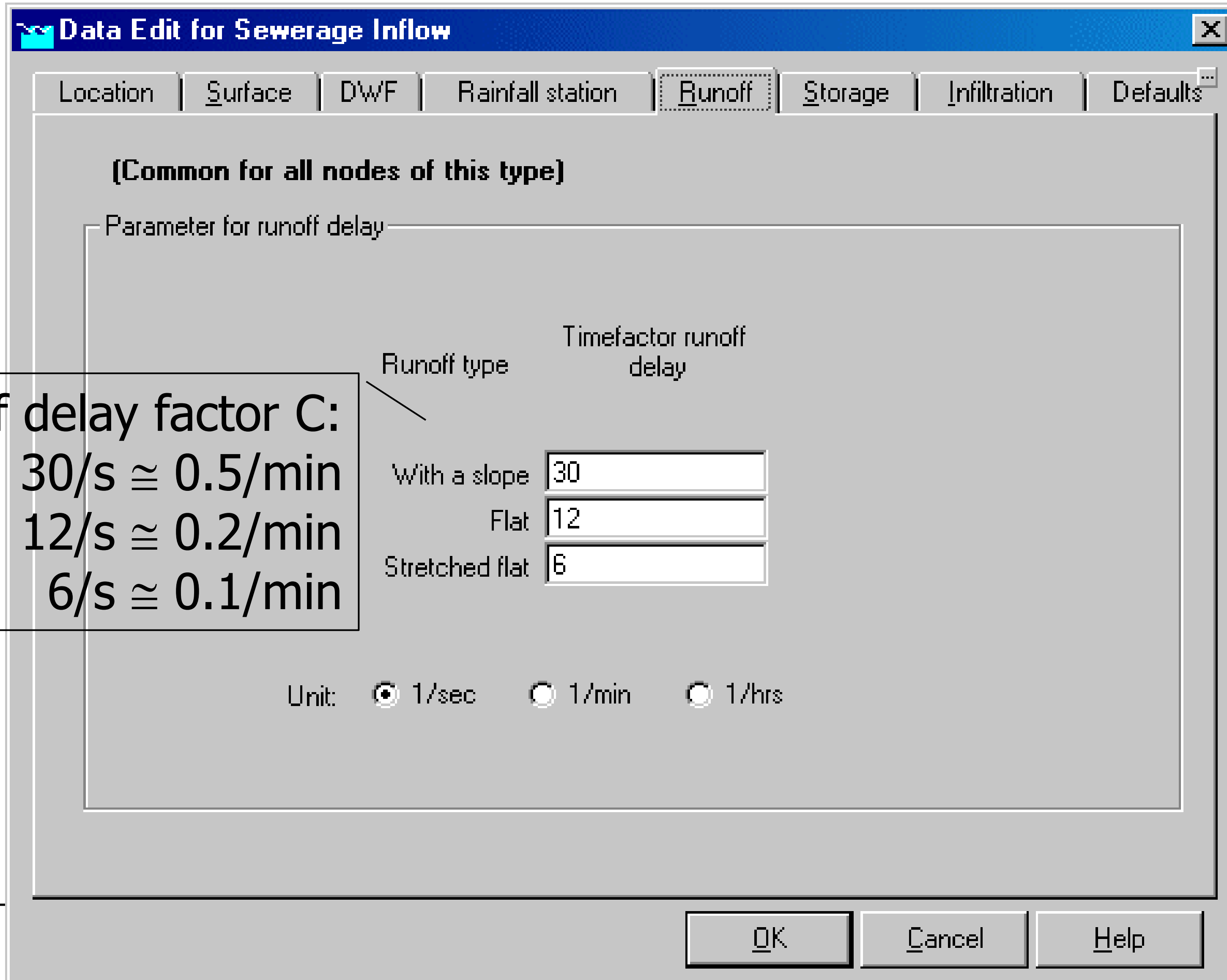
Sobek RR – Infiltration

4 area types, 4 infiltration parameters



Sobek RR – Delay coefficient (1/T)

3 area types



Runoff delay factor C:

30/s ≅ 0.5/min

12/s ≅ 0.2/min

6/s ≅ 0.1/min

Rainfall runoff module

Rainfall runoff model in Infoworks CS:

Several options:

- Fixed percentage runoff: portion of rainfall that translates into flow

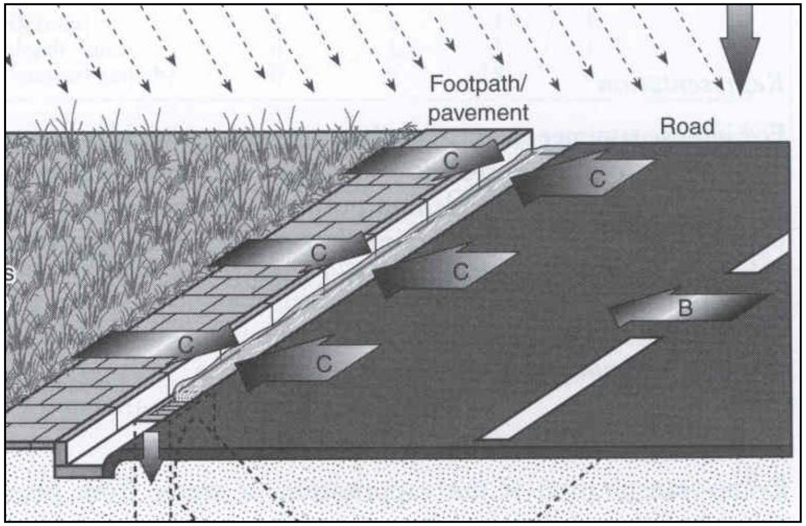
OR: 3 runoff processes

- Area storage
- Infiltration (Horton, Green-Ampt)
- Delay due to overland flow – several options:

- Several types of unit hydrograph
- Reservoir model
- “Rational method” (delay factor)

Delay due to overland flow

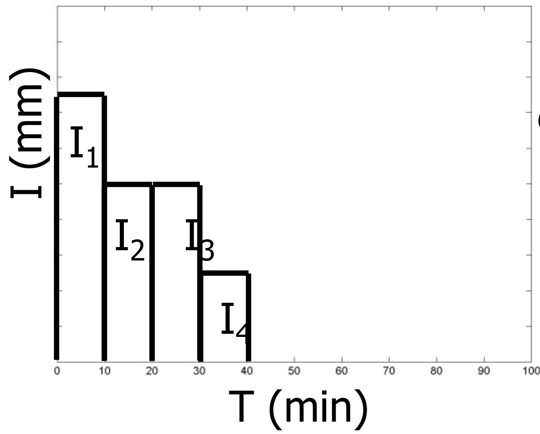
Runoff moves across surface to nearest entry point of sewer system

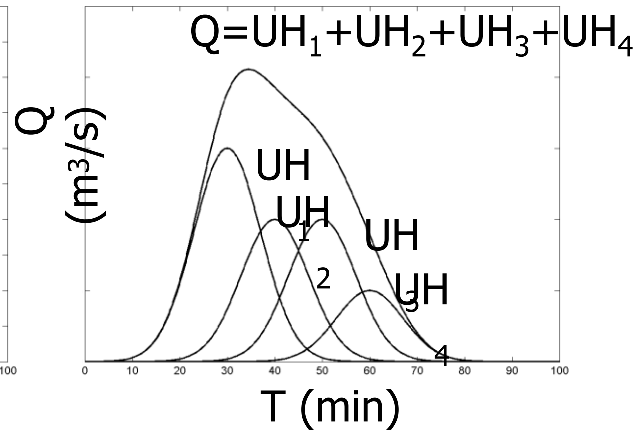


Approaches to model delay process:

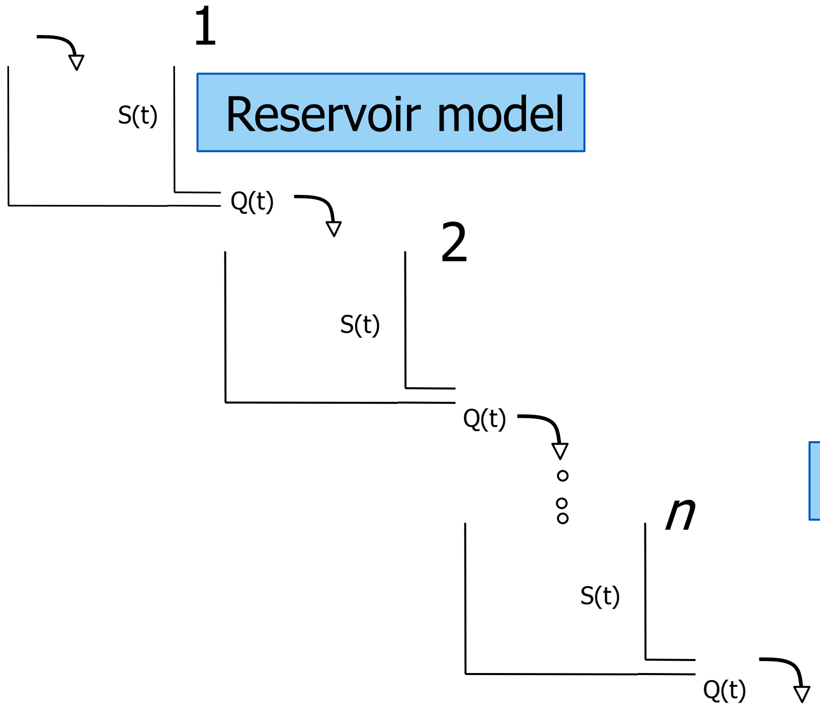
- Rational method (delay factor)
- Unit hydrograph
- Reservoir model
- Kinematic wave

(Some date from before computer-era, all still in use)





Unit hydrograph



Reservoir model

Rational method

$$Q(t) = c \cdot I$$

Kinematic wave

$$\frac{\partial d}{\partial t} + \frac{\partial q}{\partial x} = i_e$$

$$q = \frac{1}{n} d^{5/3} s^{1/2}$$

Rainfall-runoff processes, runoff model reliability

Runoff model reliability

- What parameters are included in the model ?
- What data is required to estimate those parameters ?
- How can you assess the reliability of the model ?

- Check the hydrological model you built and answer above questions

Build a hydrological model

- What parameters included ?
- What data do you need to estimate parameters?

	Parameters included	Data required
Evaporation		
Infiltration		
Depression storage		
Overland flow – delay factor C		
Overland flow – unit hydrograph		
Overland flow – reservoir model		
Overland flow – kinematic wave		

Build a hydrological model

- What parameters included ?
- What data do you need?

	Parameters included	Data required
Evaporation	- / evaporation (mm)	Temp, Humidity, wind speed, radiation
Infiltration	Min/max infiltr.cap (mm/h) decrease/recovery coeff (-)	Data series from infiltration tests
Depression storage	Storage constant per surface type (mm)	Depressions, topographical data
Overland flow – delay factor C	Delay factor C (min^{-1})	Data series I(t), Q(t) to fit delay factor
Overland flow – unit hydrograph	Unit hydrograph ordinate (m3/s)	Data series I(t), Q(t) to fit hydrograph
Overland flow – reservoir model	Reservoir constant(s) (min)	Data series I(t), Q(t) to fit reservoir const
Overland flow – kinematic wave	Roughness coefficient, terrain slope	Surface roughnesses, digital elevation model

Build a hydrological model

- What data are typically available to a modeller?

	Parameters included	Data available
Evaporation	- / evaporation (mm)	-
Infiltration	Min/max infiltr.cap (mm/h) decrease/recovery coeff (-)	-
Depression storage	Storage constant per surface type (mm)	-
Overland flow – delay factor C	Delay factor C (min^{-1})	-
Overland flow – unit hydrograph	Unit hydrograph ordinate (m3/s)	-
Overland flow – reservoir model	Reservoir constant(s) (min)	-
Overland flow – kinematic wave	Roughness coefficient, terrain slope	-

Build a hydrological model

- What parameters included ?
- What data do you need?

From meteo station near city

	Parameters included	Data required
Evaporation	- / evaporation (mm)	Temp, Humidity, wind speed, radiation
Infiltration	Min/max infiltr.cap (mm/h) decrease/recovery coeff (-)	-
Depression storage	Storage constant per surface type (mm)	Topographical data – digital elevation model
Overland flow – delay factor C	Delay factor C (min^{-1})	1/few location times series
Overland flow – unit hydrograph	Unit hydrograph ordinate (m3/s)	Idem
Overland flow – reservoir model	Reservoir constant(s) (min)	Idem
Overland flow – kinematic wave	Roughness coefficient, terrain slope	Digital elevation model

NB: resolution

Hydrological model reliability

- Epistemic uncertainties ?
- Aleatory uncertainties ?

	Parameters included	Data required
Evaporation	- / evaporation (mm)	Temp, Humidity, wind speed, radiation
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Hydrological model reliability

- Epistemic uncertainties ?
- Aleatory uncertainties ?

NB: subsidence

Natural variations in roughness

	Parameters included	Data required
Evaporation	- / evaporation (mm)	Temp, Humidity, wind speed, radiation
Infiltration	Min/max infiltr.cap (mm/h) decrease/recovery coeff (-)	Data series from infiltration tests
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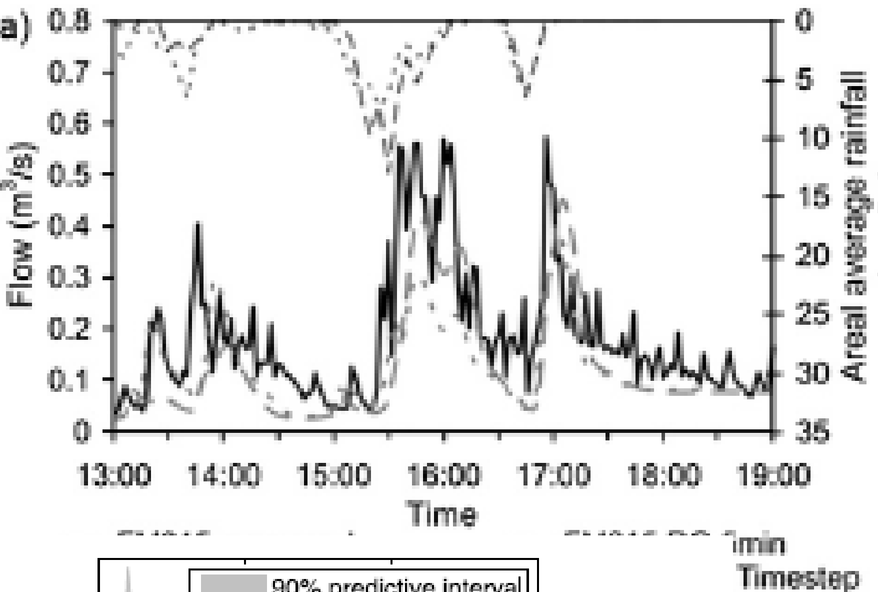
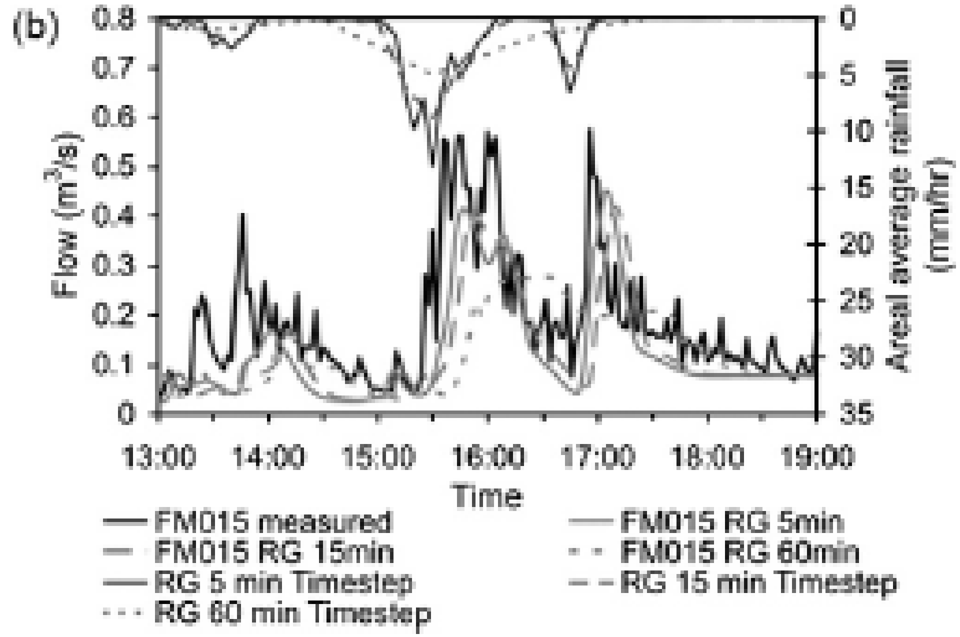
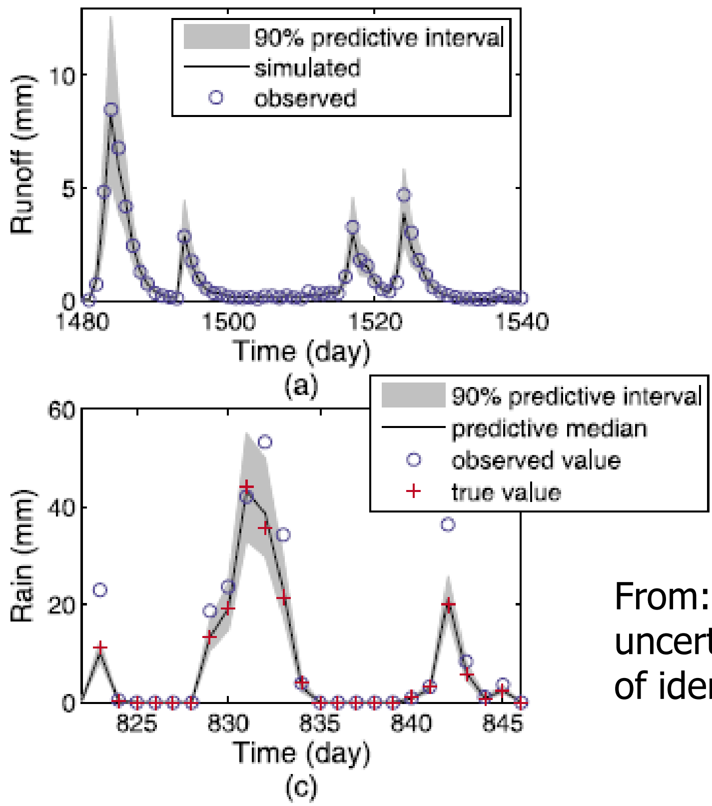


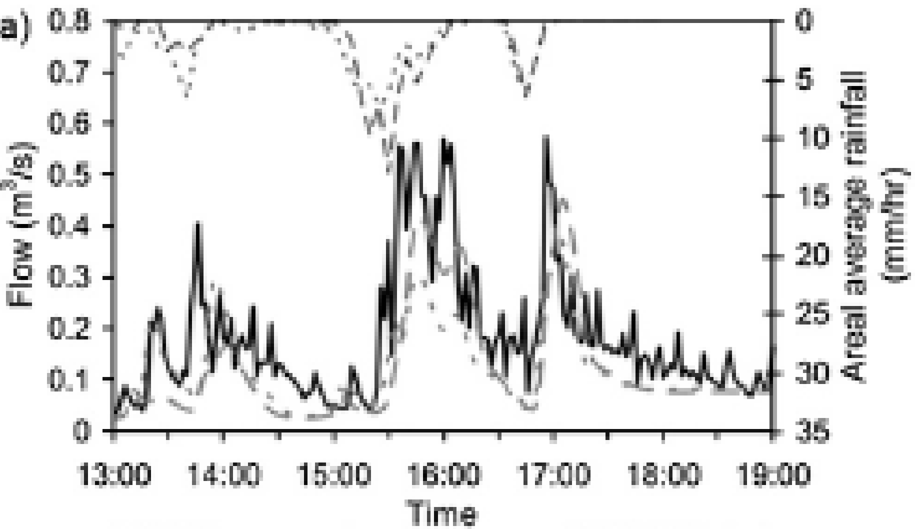


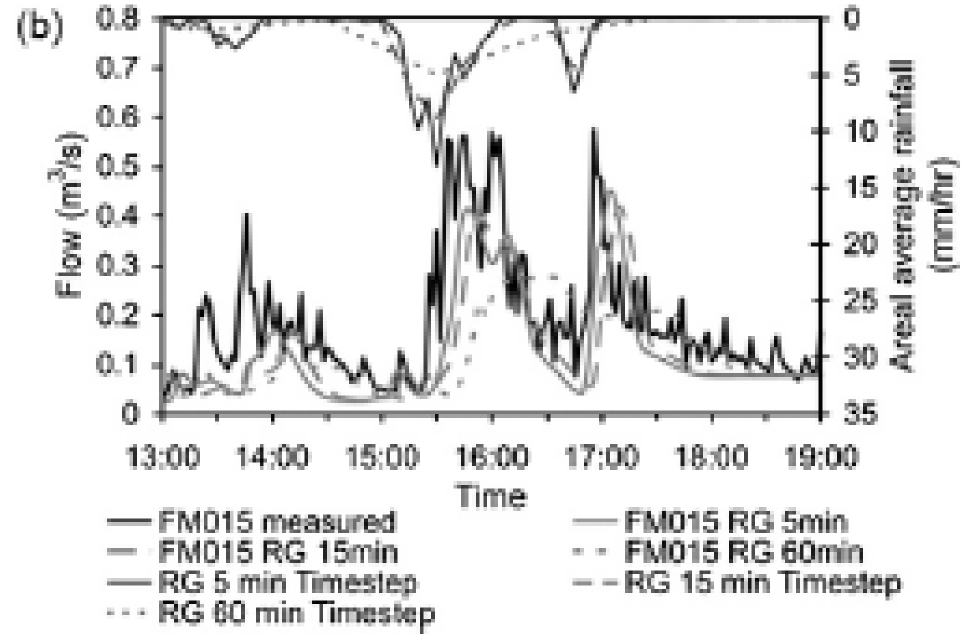
From: Schellart et al. 2012. Influence of rainfall estimation error and spatial variability on sewer flow prediction at a small urban scale



- ➢ Models fit for observations at 1/few locations
- ➢ this is the problem of overparameterisation, leading to equifinality (multiple solution can fit)

From: Renard et al. 2010. Understanding predictive uncertainty in hydrologic modeling - the challenge of identifying input and structural errors





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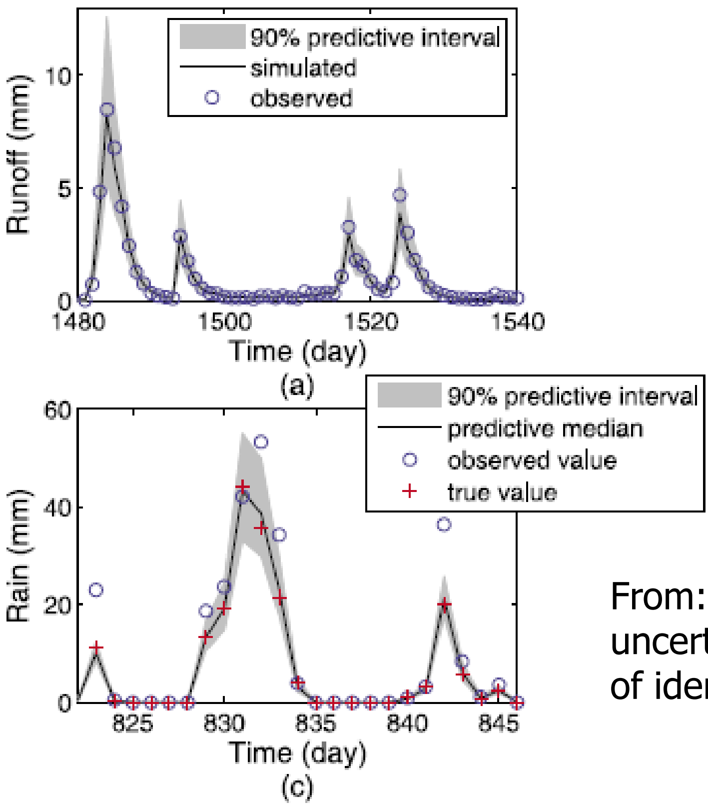

- Models fit for observations at 1/few locations
- Model uncertainty must be made explicit

From: Renard et al. 2010. Understanding predictive uncertainty in hydrologic modeling - the challenge of identifying input and structural errors