Pumping stations and water transport

Network calculations
ct5550

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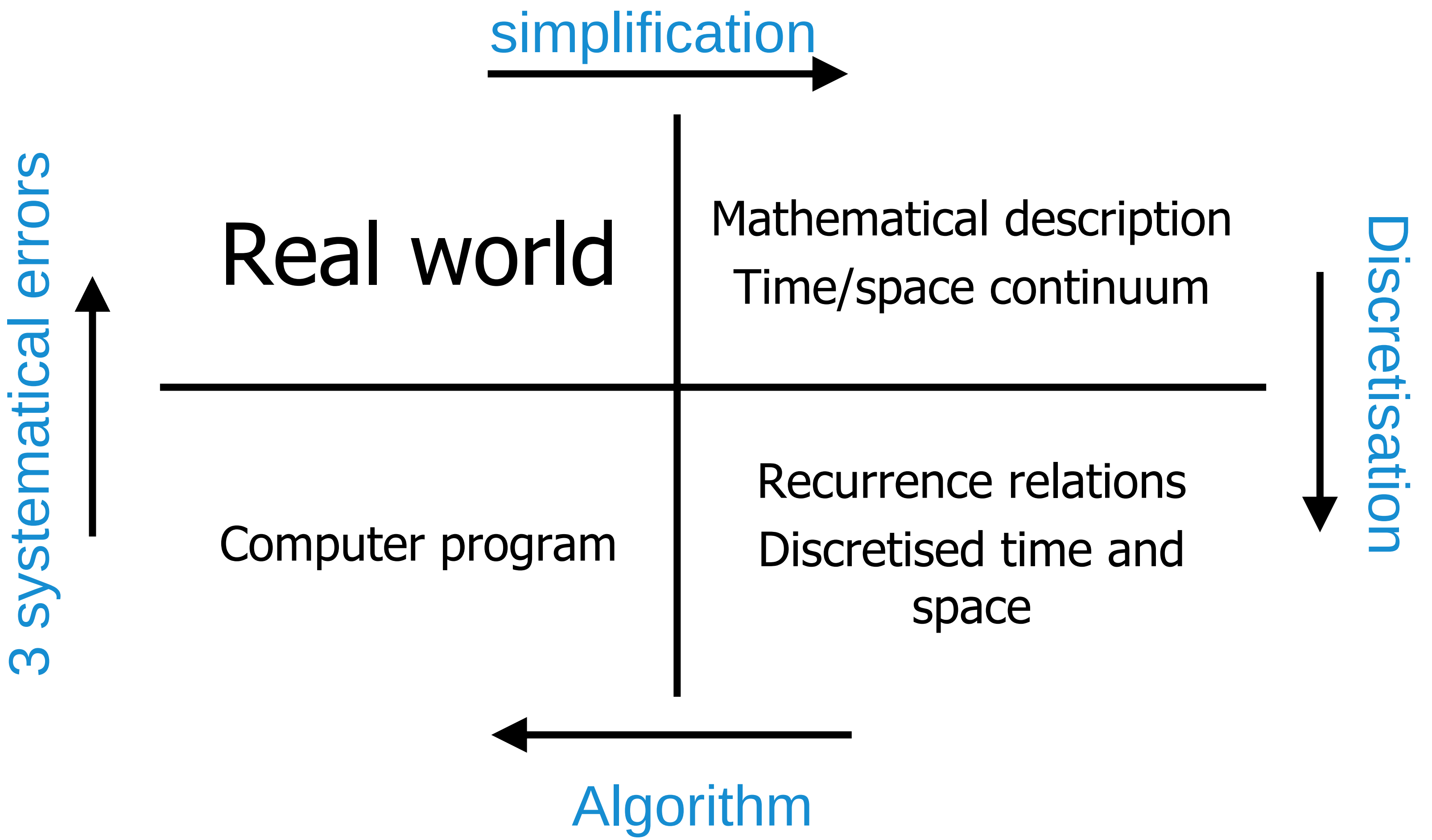
Delft University of Technology

Introduction

- Pipe networks are complicated systems
- Analysing networks needs computer simulation
- Two types of modelling:
  - Sewerage or urban drainage models: open channel flow and transition periods
  - Drinking water: pressurised pipe

From reality to calculation



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(3 systematic errors)

Drinking water modelling: filled pipe, basic equations

- Darcy Weisbach

$$\Delta H = H_2 - H_1 = \lambda \frac{L}{D} \frac{v^2}{2g} = 0{,}0826 \frac{\lambda L}{D^5} Q^2$$

- White - Colebrook

$$\frac{1}{\sqrt{\lambda}} = -2 \log \left[\frac{k_N}{3D} + \frac{1}{0{,}32 \, \mathrm{Re} \sqrt{\lambda}} \right]$$

- One equation with one unknown

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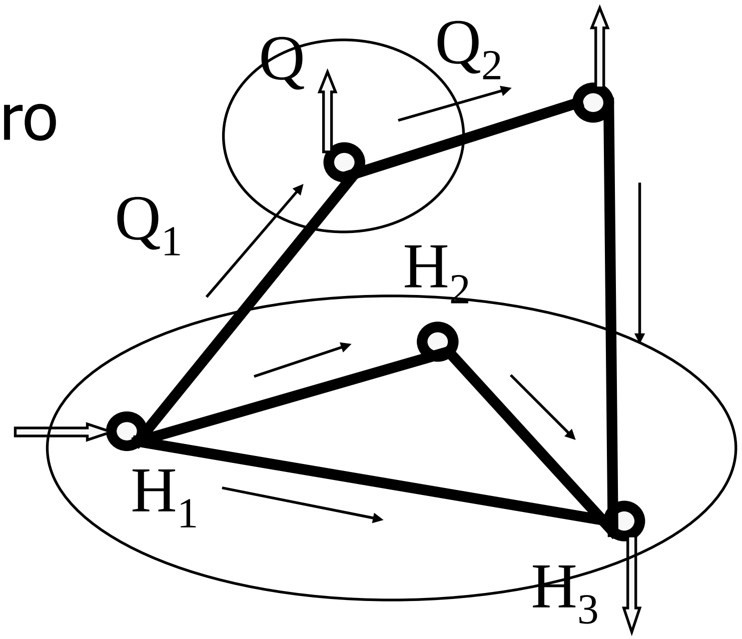
Kirchhoff's laws

- Mass balance in a node is zero
  $Q_1-Q_2-Q=0$
- Pressure losses in a loop is zero
  $(H_2-H_1)+(H_3-H_2)+(H_1-H_3)=0$



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Set of equations

- Consider a network with N nodes and X pipes
- $Q^2_x = f(\Delta H_n) = f(H_n - H_{(n-1)})$
- X equations with N unknown
- N node-equations ($\Sigma Q_x = 0$)
  with n (H_n) unknown
- Reduced to a set of N equations with N unknown
- Complication: non-linear relation between
  Q and H

Solving methods

- Hardy-Cross: pressure equalisation method
  - Assume pressures in all nodes
  - Take one node and adjust pressure until mass balance equals zero (Kirchhoff's first law)
  - Take next node and adjust pressure until….
  - Repeat until $\Delta p <$ threshold
- Can be done manually
- First computerised calculations

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Solving methods

- Hardy-Cross: volume flow equalisation method
  - Assume pressures in all nodes
  - Take one loop and adjust volume flows with ΔQ until sum of pressure losses equals zero (Kirchhoff's second law)
  - Take next loop and.....
  - Calculate pressures and repeat flow adjustments until ΔQ < threshold
- Computerised calculations

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Solving methods: Linear programming

- Linearisation:
  $Q^2_x = f(\Delta H_n) => Q^*_x * Q_x = R(H_2 - H_1)$
- With an estimation of Q the equations become linear and can be solved with matrices (n*n symmetric matrix)
- Iteratively the solution is found
  - Estimated Q^*_x is corrected with calculated Q_x, and so on
- Only possible with computers: memory is no longer a limitation

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Accuracy of the calculation

- Lots of data necessary to calculate the pressures and volume flows
- 10% error in diameter gives 40% error in pressure drop

$$\Delta H = 0{,}0826 \frac{\lambda L}{D^5} Q^2$$

$$\text{error } \Delta \text{H} : \frac{1}{1{,}1^5} = 0{,}62 \Delta H$$

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Accuracy of the calculation

- 10% error in volume flow gives 20% error in pressure drop

$$\Delta H = 0{,}0826 \frac{\lambda L}{D^5} Q^2$$

$$\text{error } \Delta \text{H} : 1{,}1^2 = 1{,}21 \Delta H$$

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Accuracy of the calculation

- 10% error in length gives 10% error in pressure drop

$$\Delta H = 0{,}0826 \frac{\lambda L}{D^5} Q^2$$

$$\text{error } \Delta \text{H} : 1{,}1 \Delta H$$

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Some roughnesses

Material	K-value	Source
CI <= 200	5	E/L
CI > 200	2	E/L
CI lined on site	0.5	R
CI Factory lined	0.2	M
AC	0..2	M
Concrete	0.5	E/L
PE	0.05	M
PVC	0.05	M
Steel bitumous lined	1.5	L
Steel cement lined	0.2	M

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Different resistance formulas

$$\Delta H = a \cdot Q^{b-1}|Q|$$

Name	Res coef (a)	Exp (b)
Darcy Weisbach	$\frac{8\lambda L}{\pi^2 g D^5}$	2
Hazen-Williams	$\frac{2{,}79 * 10^{-6} L}{C^{1{,}85} D^{4{,}87}}$	1,85
Chezy-Manning	$\frac{7{,}97 * 10^{-7} n^2 L}{D^{5{,}33}}$	2

Boundaries

- Nodes
  - Demand (positive is demand)
  - Supply (negative is supply)
  - Fixed pressure head
- Pipes
  - Resistance
  - Special resistance : pump
  - Different types of valves (check valve, PRV, PSV, PBV, FCV, TCV

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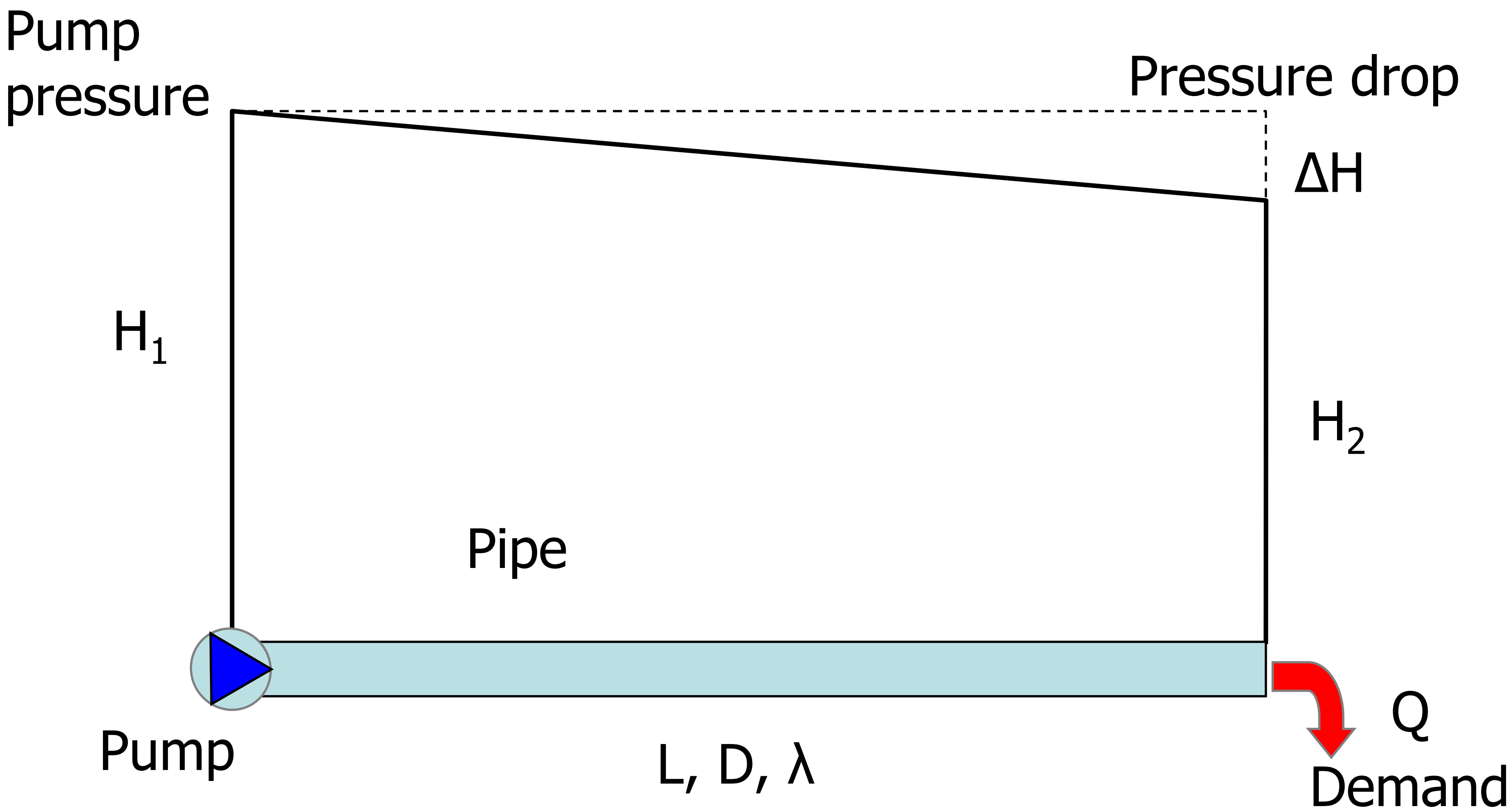
Accuracy in measuring



Water quality calculations

- Mass balance

$$\frac{\partial c_{ij}}{\partial t} = \frac{Q_{ij}}{A_{ij}} \frac{\partial c_{ij}}{\partial x_{ij}} + \Theta\left(c_{ij}\right)$$

- Solved for known boundary conditions

$$c_{ij}(0,t) = \frac{\sum_k Q_{ki} c_{ki}(L_{ki}, t) + M_i}{\sum_k Q_{ki} + Q_{si}}$$

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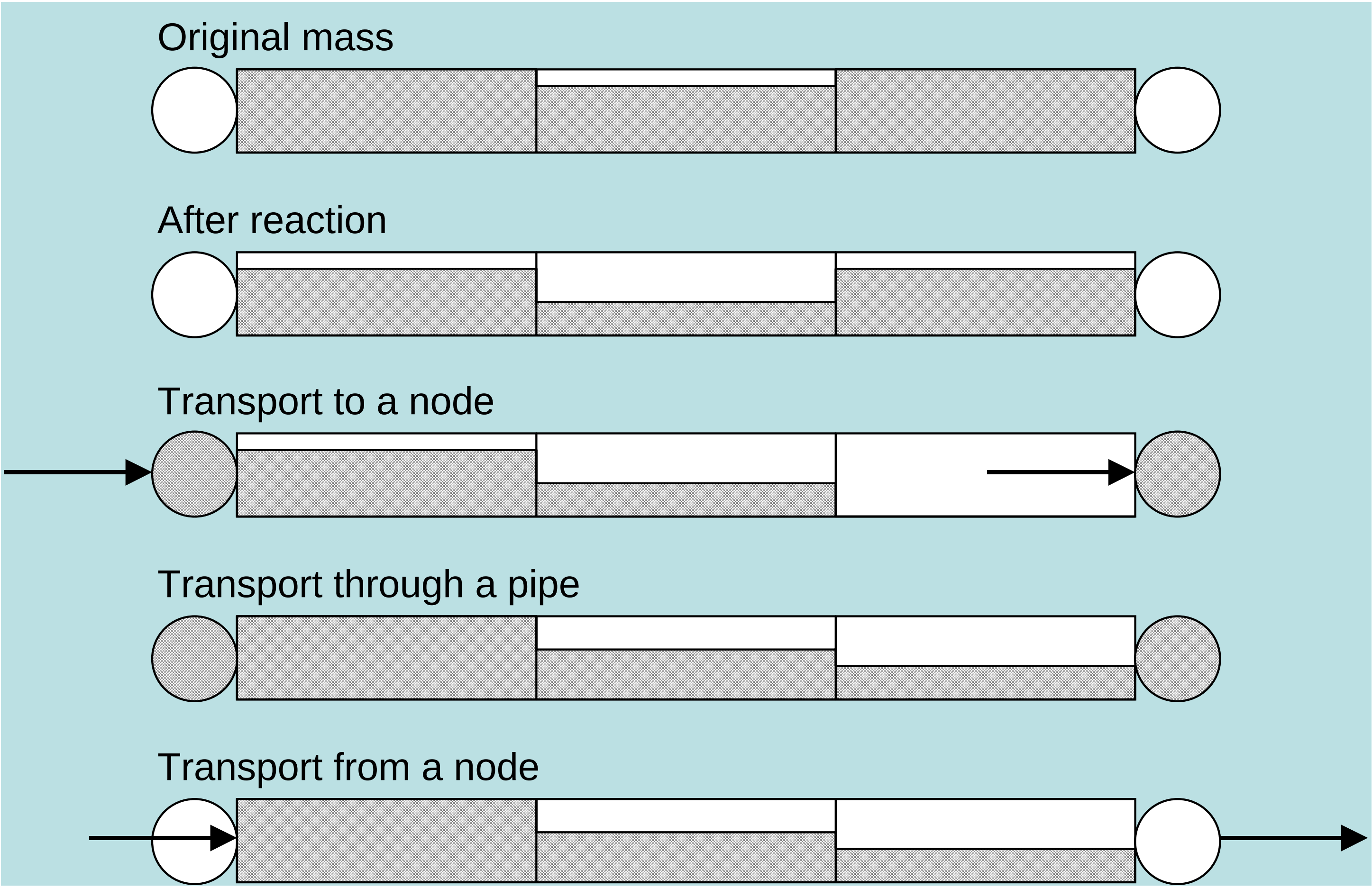
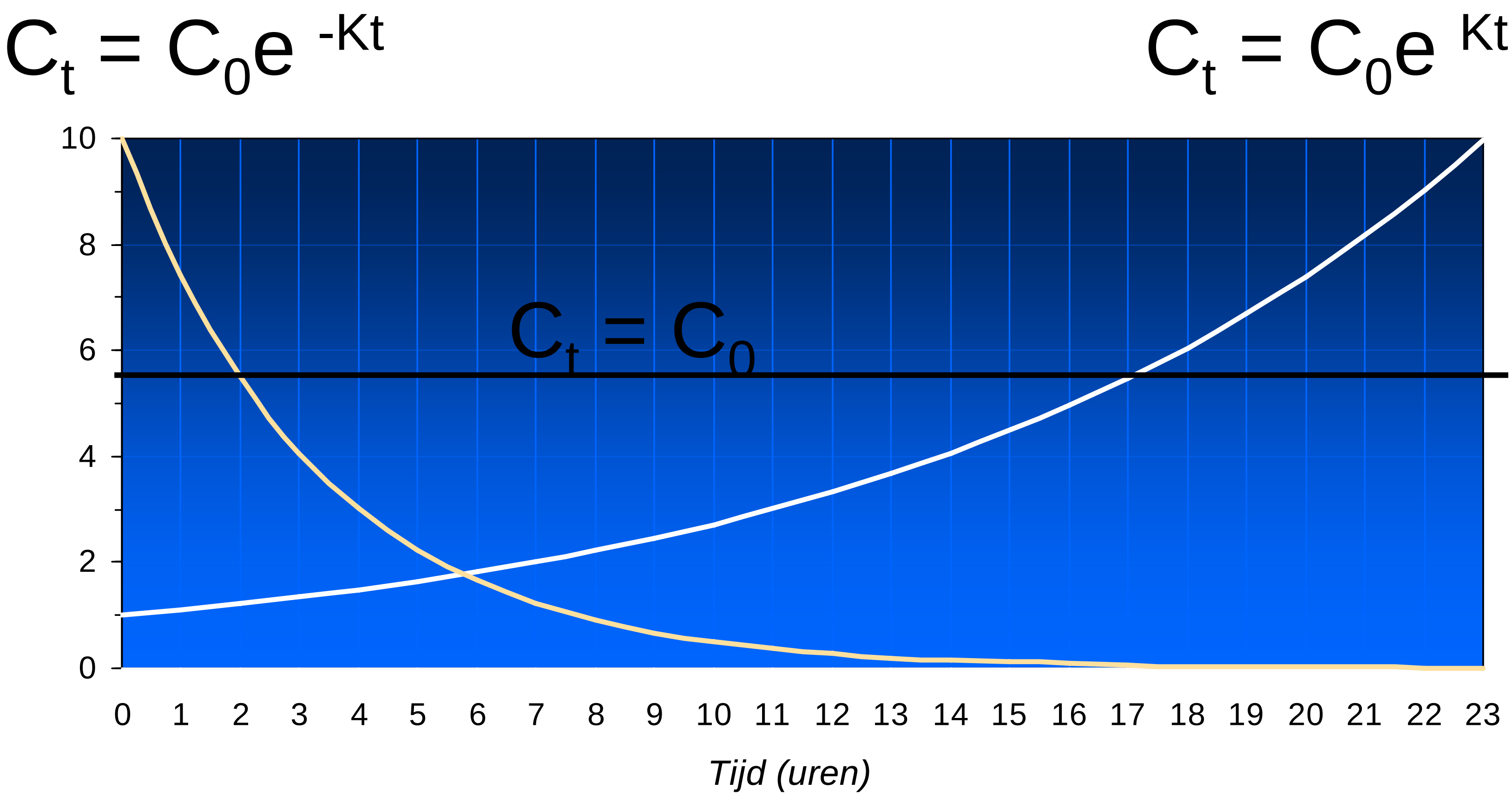
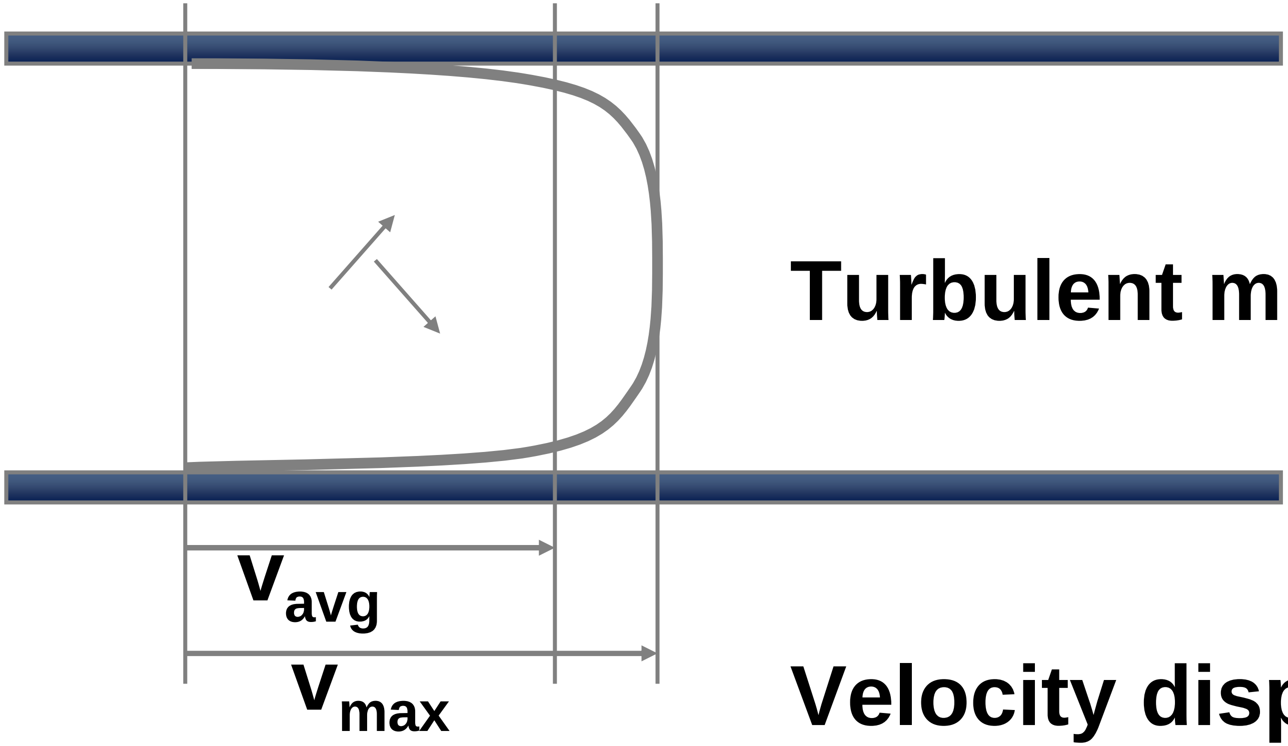
Water quality algorithm



Reaction model examples



Reality is more complicated



Turbulent mixing

Velocity dispersion

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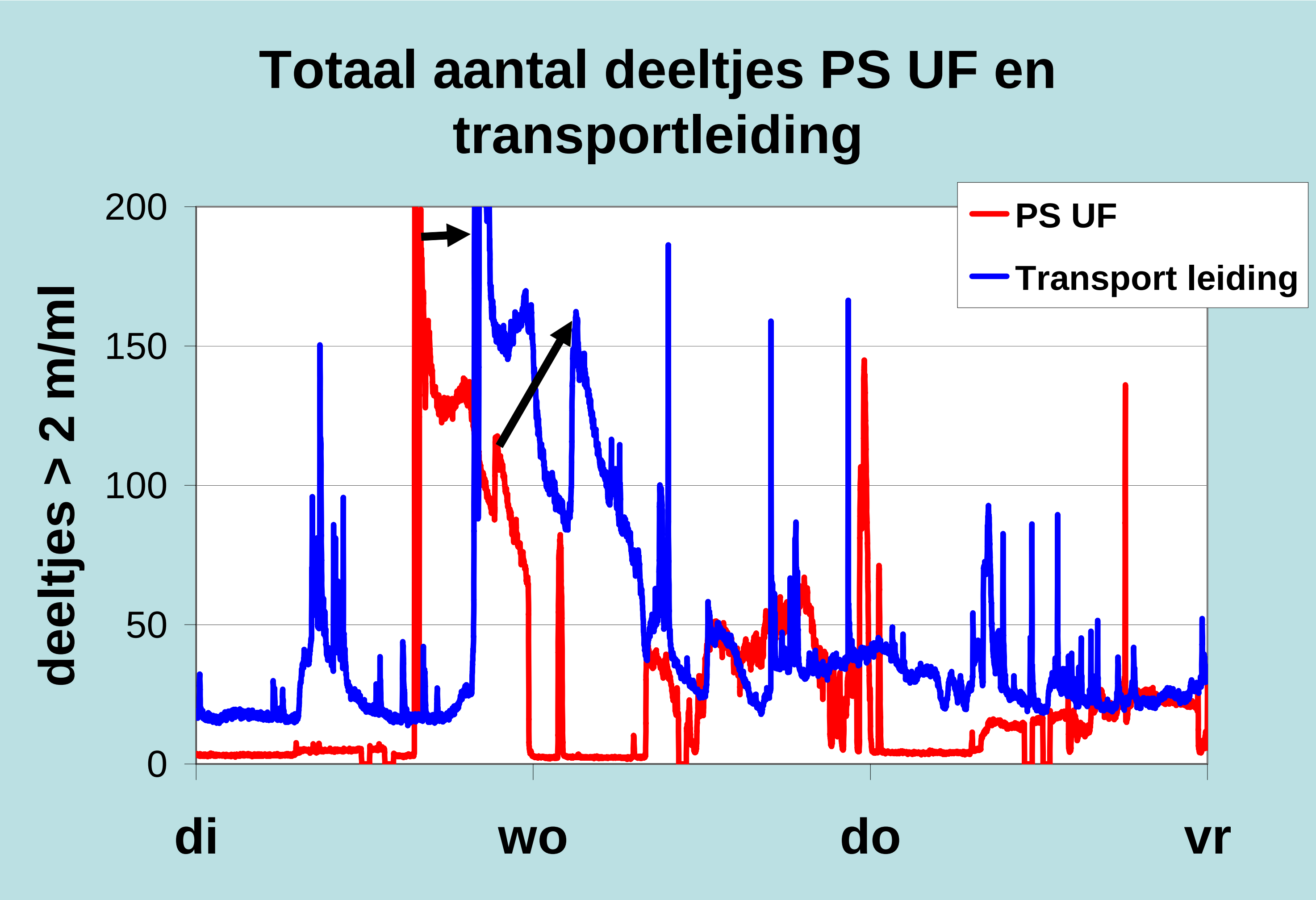
But also encouraging



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To read some more

- Appendix E Aleid manual (blackboard)
- Lewis Rossman EPA

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Open channel flow / urban drainage

- De Saint Venant equations are translated into finite difference equations
- Time dependency is most important difference with surcharged pipes

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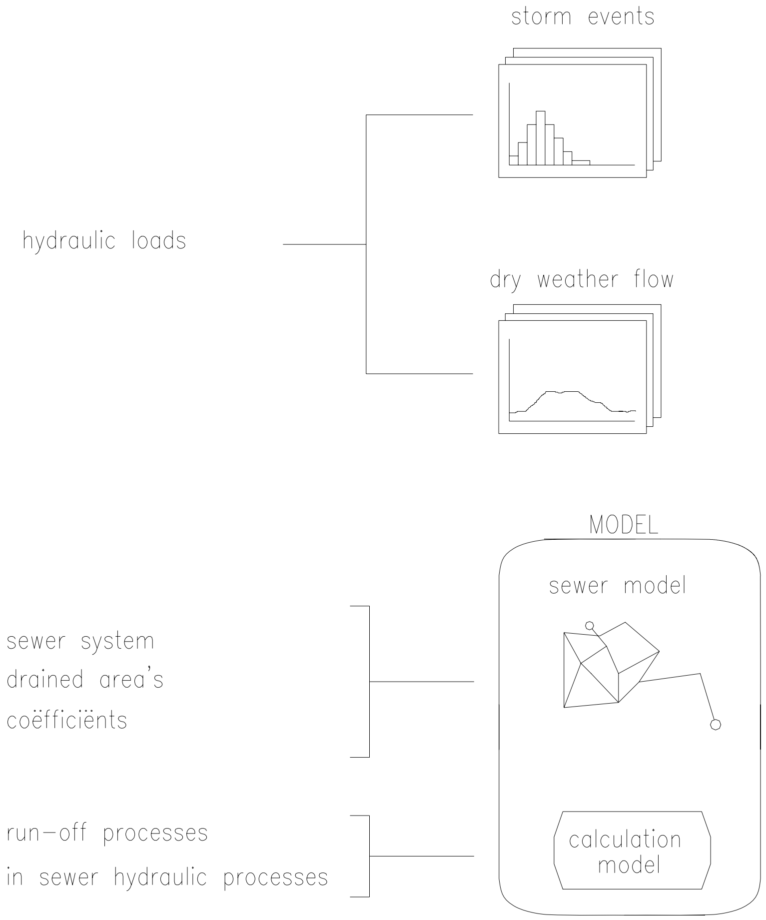
Processes in urban drainage modelling

- The hydraulic process, modelled in a numerical model
- Geometrical description: model of pipes and joints, ect
- Hydraulic load under dry weather and storm conditions

Components in urban drainage modelling



Loads urban drainage

- Dry Weather Flow (DWF)
  - Domestic wastewater
  - Industrial wastewater
  - Drain water due to leakage
- Data for domestic wastewater has conformity with drinking water supply
- Drain water can be up to 50%!

Loads urban drainage

- Storm conditions
  - Wetting of dry surface
  - Infiltration
  - Storage in local surface depressions
  - Evaporation
  - Overland flow

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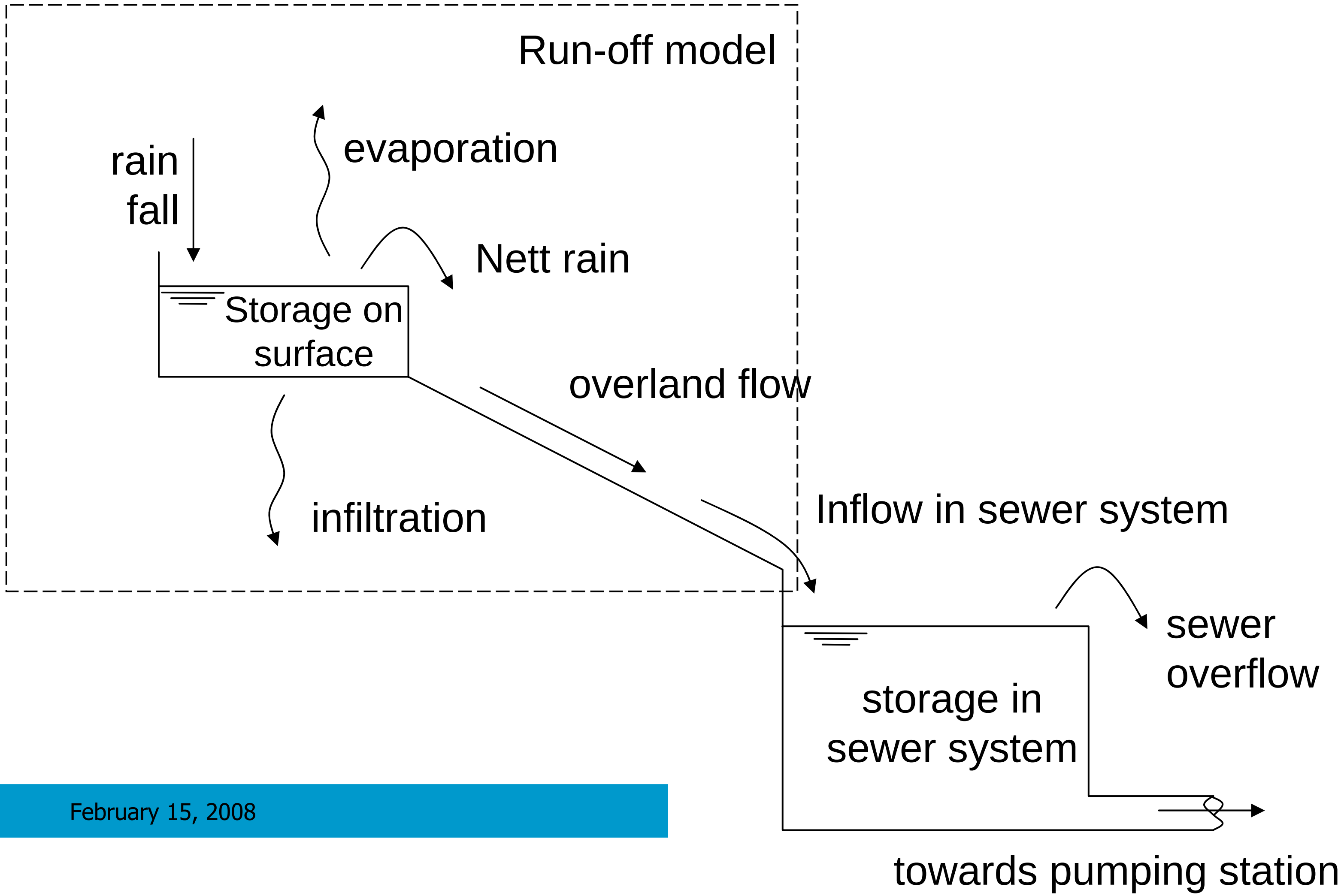
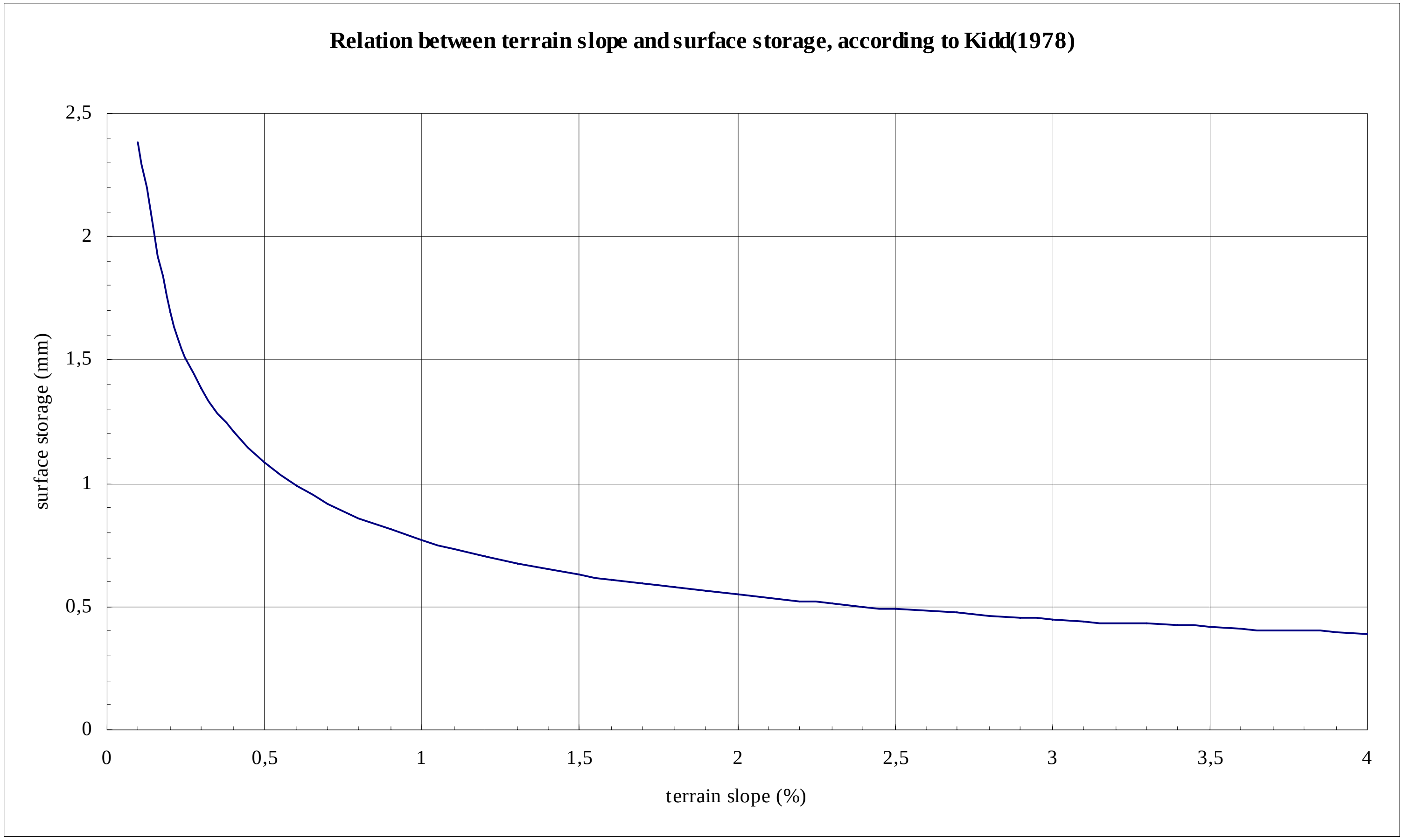
Loads urban drainage, storm conditions



Storage on local surface



Evaporation and infiltration

- Evaporation dependent on various factors
  (temperature, wind speed, colour of surface, etc)
- Practical approach:
  - Neglect during individual storms or give a constant value
- Infiltration dependent on various factors
  (saturation, groundwater level, surface, etc)
- Practical approach:
  - Constant rate model

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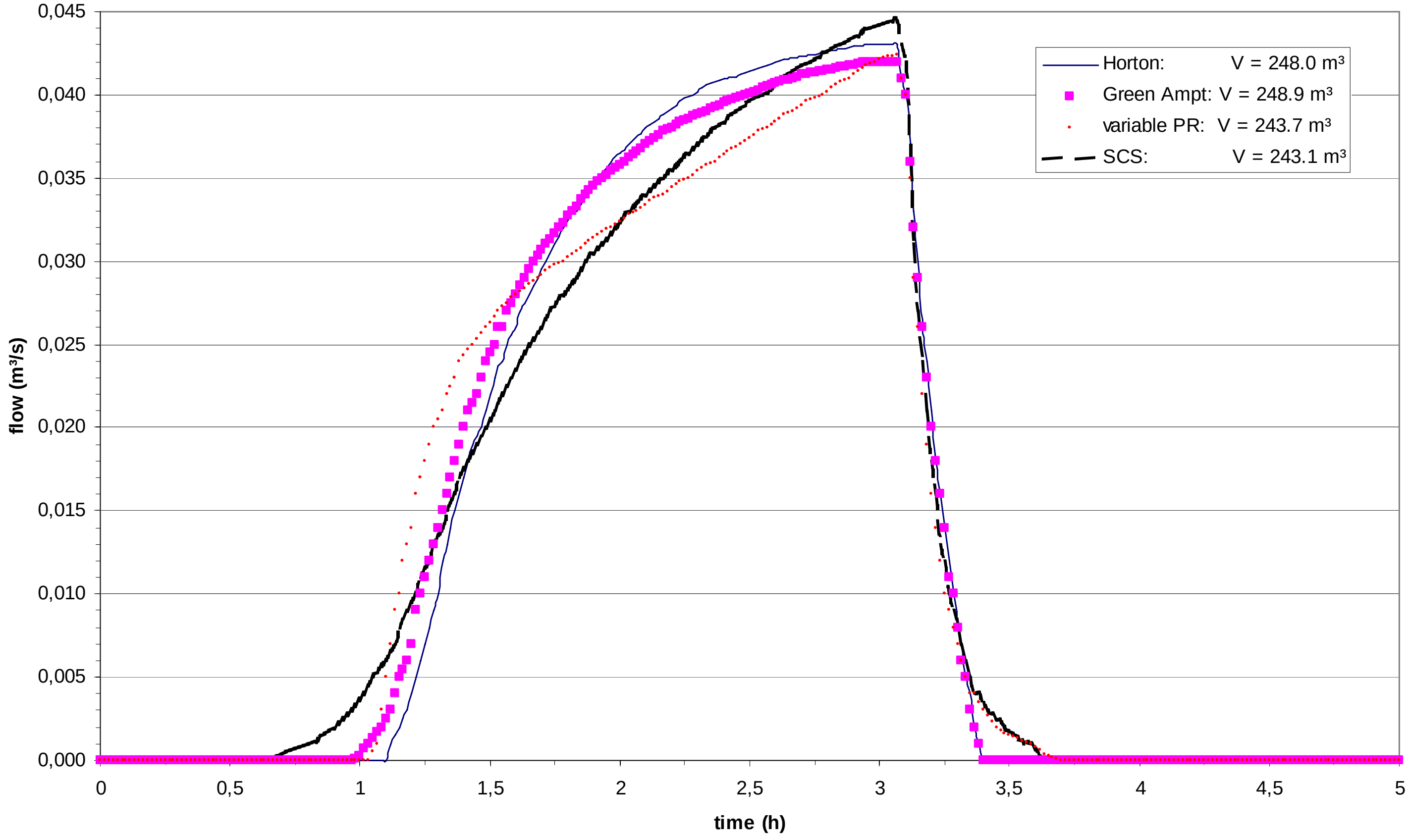
Run-off

- Run-off occurs when ‘all is saturated’
- Several models available (annex to lecture notes, see also Thesis Clemens)
- Practical approach: Simple models with the smallest number of parameters

Performance run-off models



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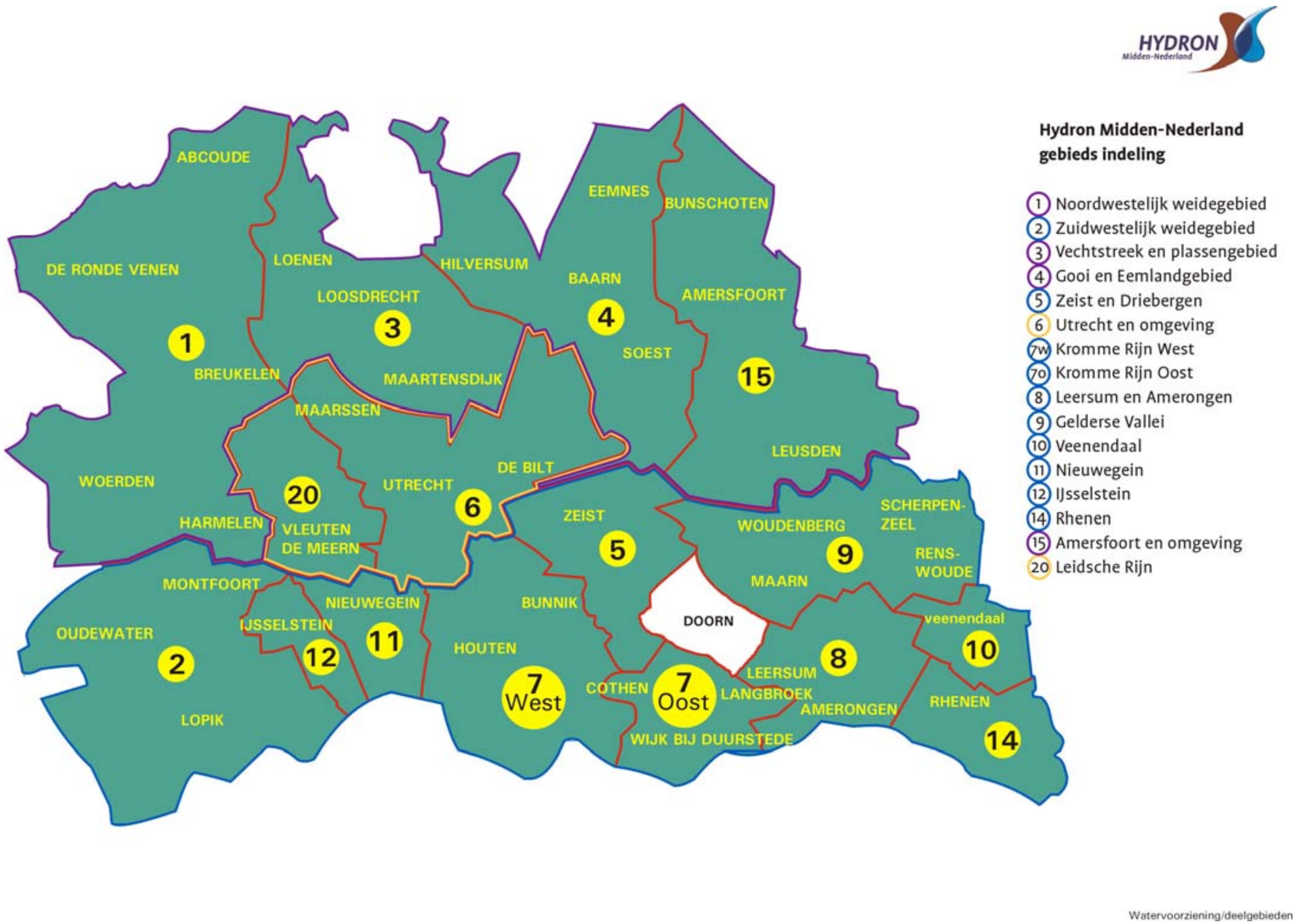
Build up of a network model

- Simulation of flow and pressure
- Risk management:
  - Reliability assesement at calamities and planned activities
- Operation:
  - Design major structure
  - Balancing production
  - Water quality and cleaning

Model build up town Utrecht

- Determine area boundaries and level of schematisation
- Water balance and pipe model
- Demand allocation and modulation
- Modelling supply and installation controls
- Model verification
- Report and knowledge transfer

Service areas



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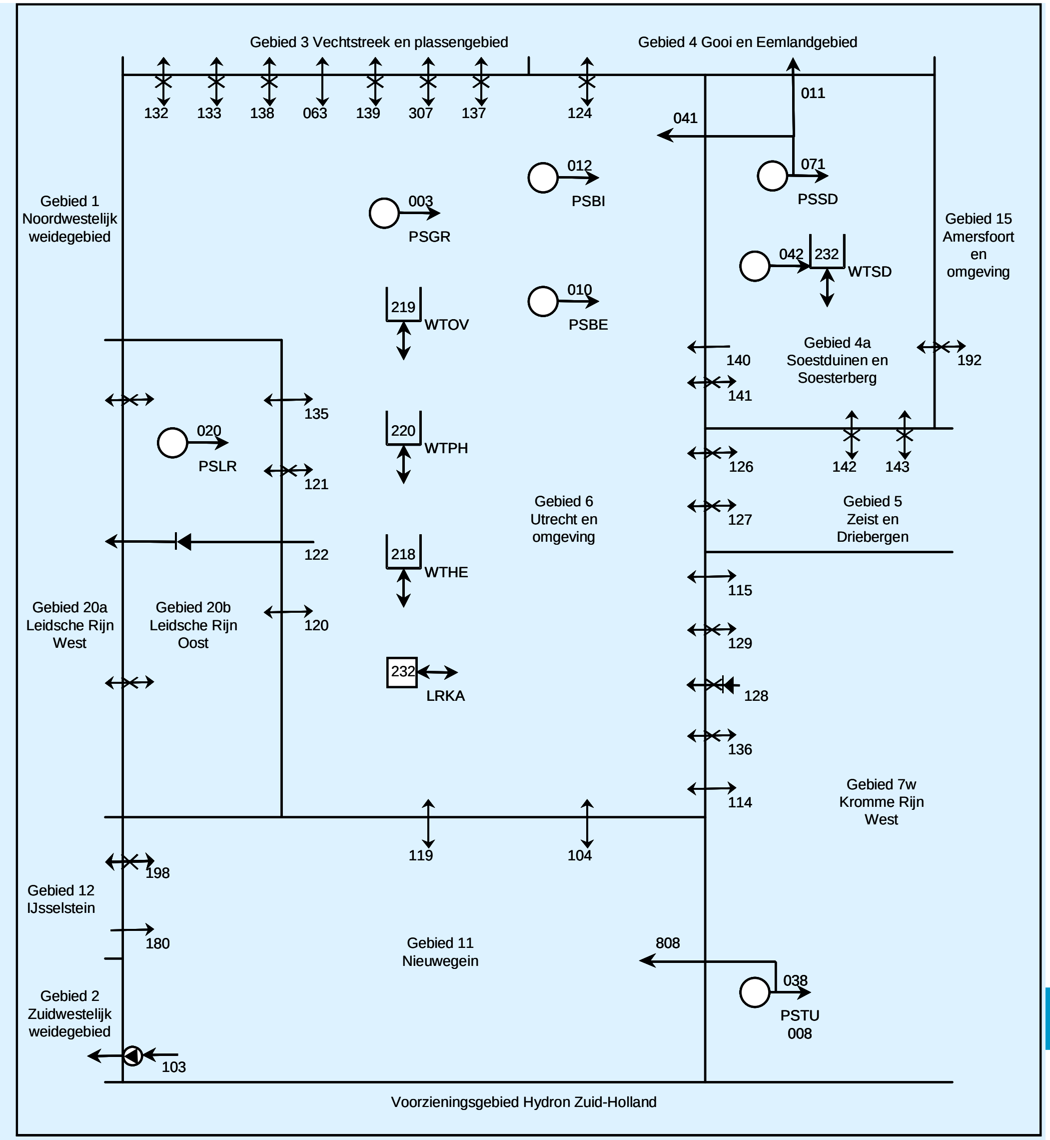
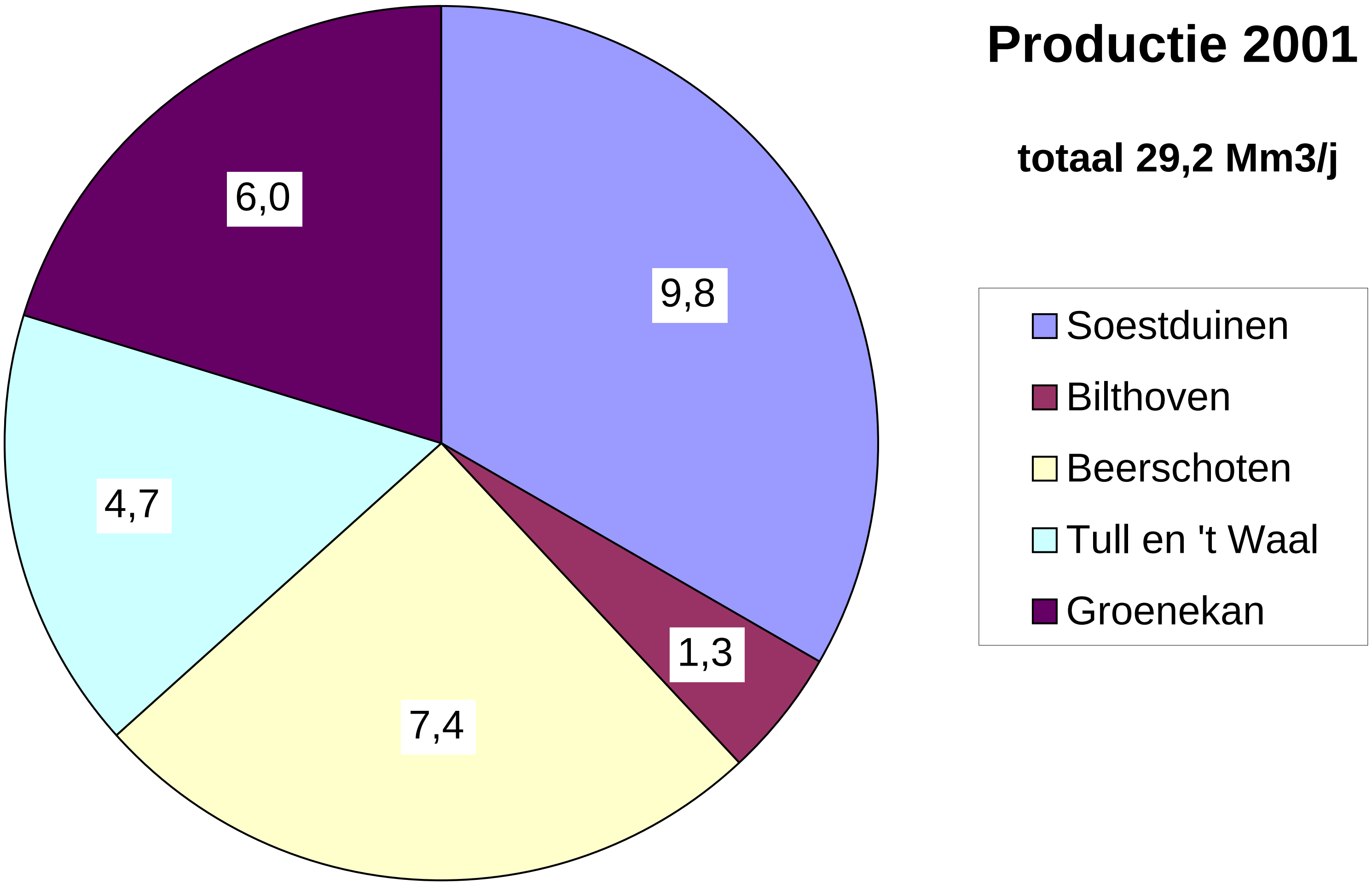
Schematisation model area

- Sub areas
- Pumping stations
- Reservoirs
- Connection points



Water balance 2001 (in)



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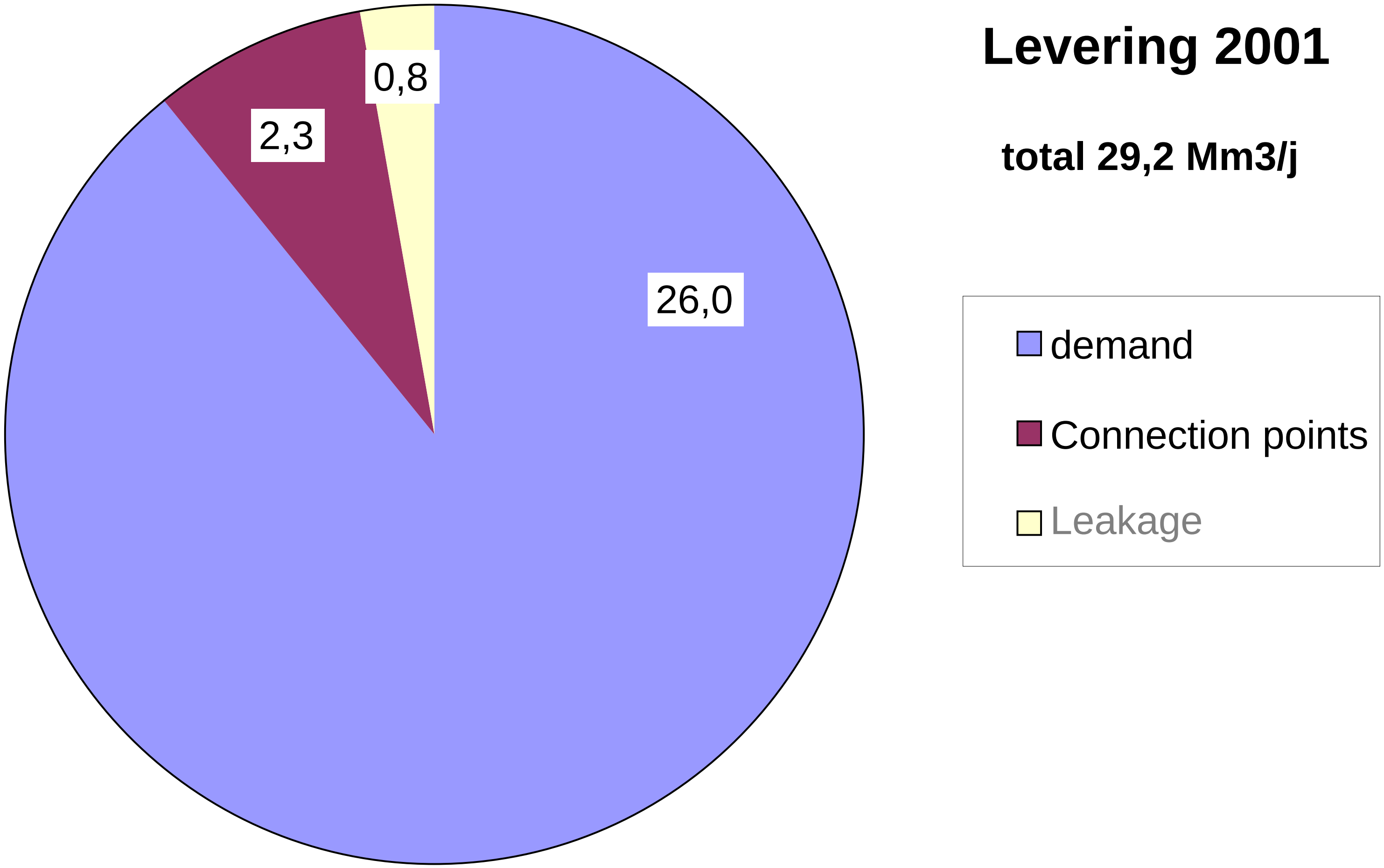
Water balance 2001 (uit)



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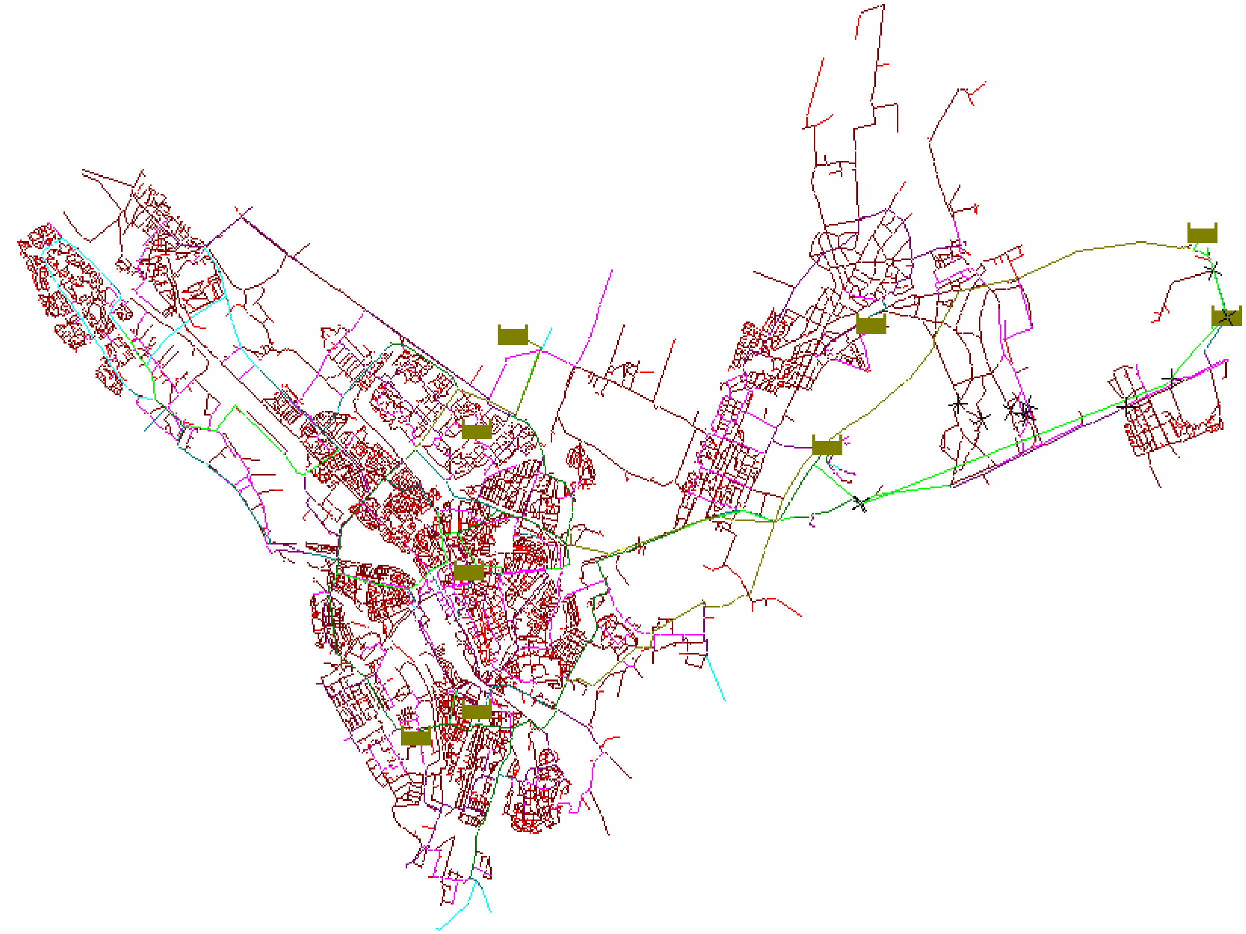
Network area 6 and 4 south

20.177 nodes en 23.268 pipes



Industrial Nieuwegein 2001 (source: VIS)

perceelnr	*postcode*	*huisnr*	*verbr_code*	*verbr_vis2*	*klantnaam*	*straat*
164939	3435CM	1	3	91827	ST Antonius Ziekenhuis	Koekoekslaan
160625	3432GN	1	3	55562	NV Sportinr. Nieuwegein	Merweplein
1006917	3439LC	100	3	25649	Pen.Inr.UT locatie N'gein	De Liesbosch
149835	3432NZ	11	3	22135	Henkel Ecolab BV	Brugwal
160715	3433PE	5	3	21249	Kiwa NV	Groningenhaven
149842	3439MN	14	3	18171	Fom Instituut Rijnhuizen	Edisonbaan
171597	3437JG	1	3	15760	Stg Portaal Utrecht	Colijnpark
171602	3439LB	6	3	15361	Transportbeton Pioneer V.	De Liesbosch
170092	3437PD	77	3	13784	St.Altrecht FCI cred.adm.	Rembrandthage
165127	3435SB	2	3	13102	BV Expl Maats Poort v Nge	Buizerdlaan
170218	3439NT	80	3	12801	PTT Post BV / Fin.Adm.	Grote Wade
150723	3431SH	91	3	12514	Mitros Wonen	Nijpelsplantsoen
1						Nijpelsplantsoen
1						Nijpelsplantsoen
10					ı WPM.	Winkelcentrum Galecop
1						Nijpelsplantsoen

Kiwa ‘used’ in 2001 2,4 m3/uur on avarage

(365 dagen/jaar; 24 hour/day) circa € 100/werkdag

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Drinking water supply Kiwa

- 21249 m3/year
- Industrial/office: 50 weeks of 5 days, 10 hours per day, 140 persons
- Avarage hourly consumption 60 litre per person
- Avarage houshold consumption
  130 lpppd

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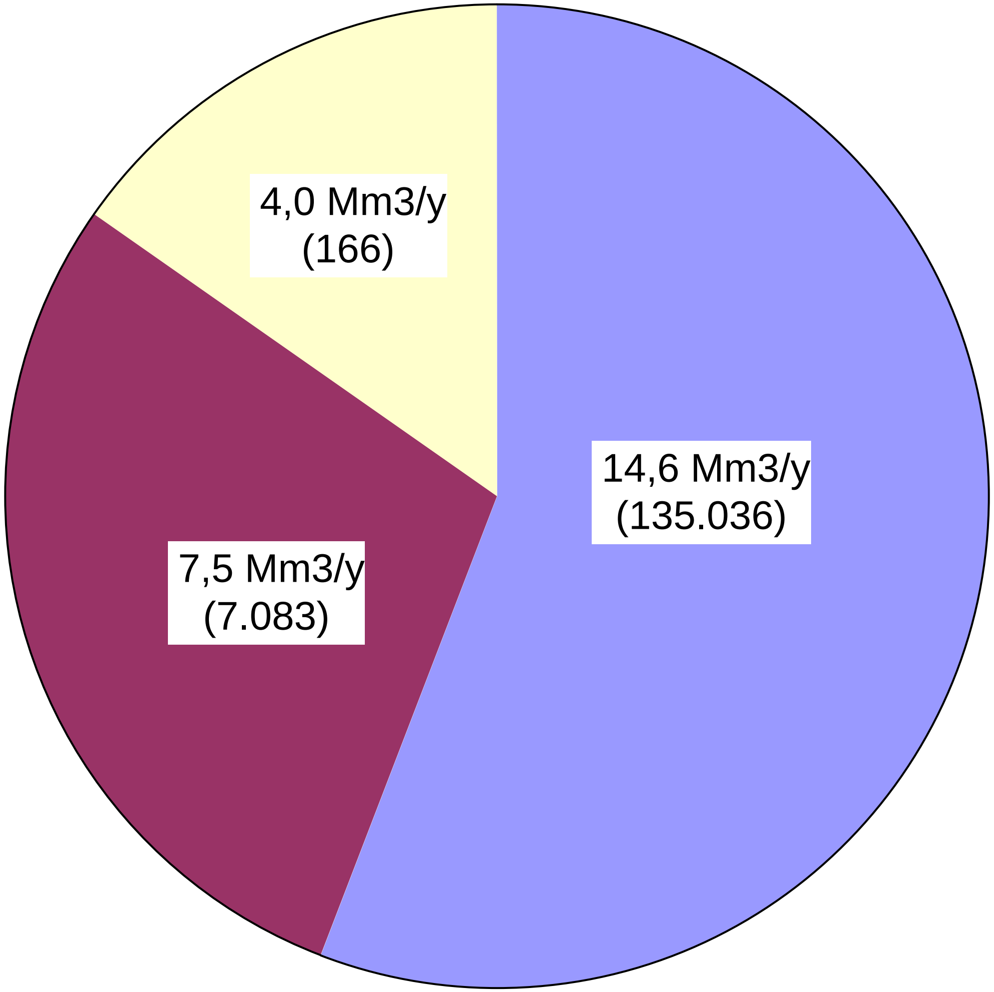
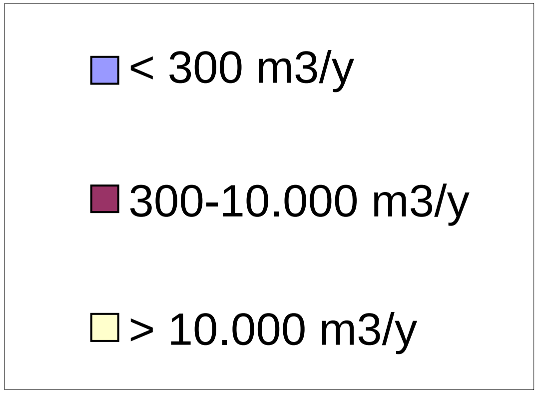
Supply in 2001 (VIS)



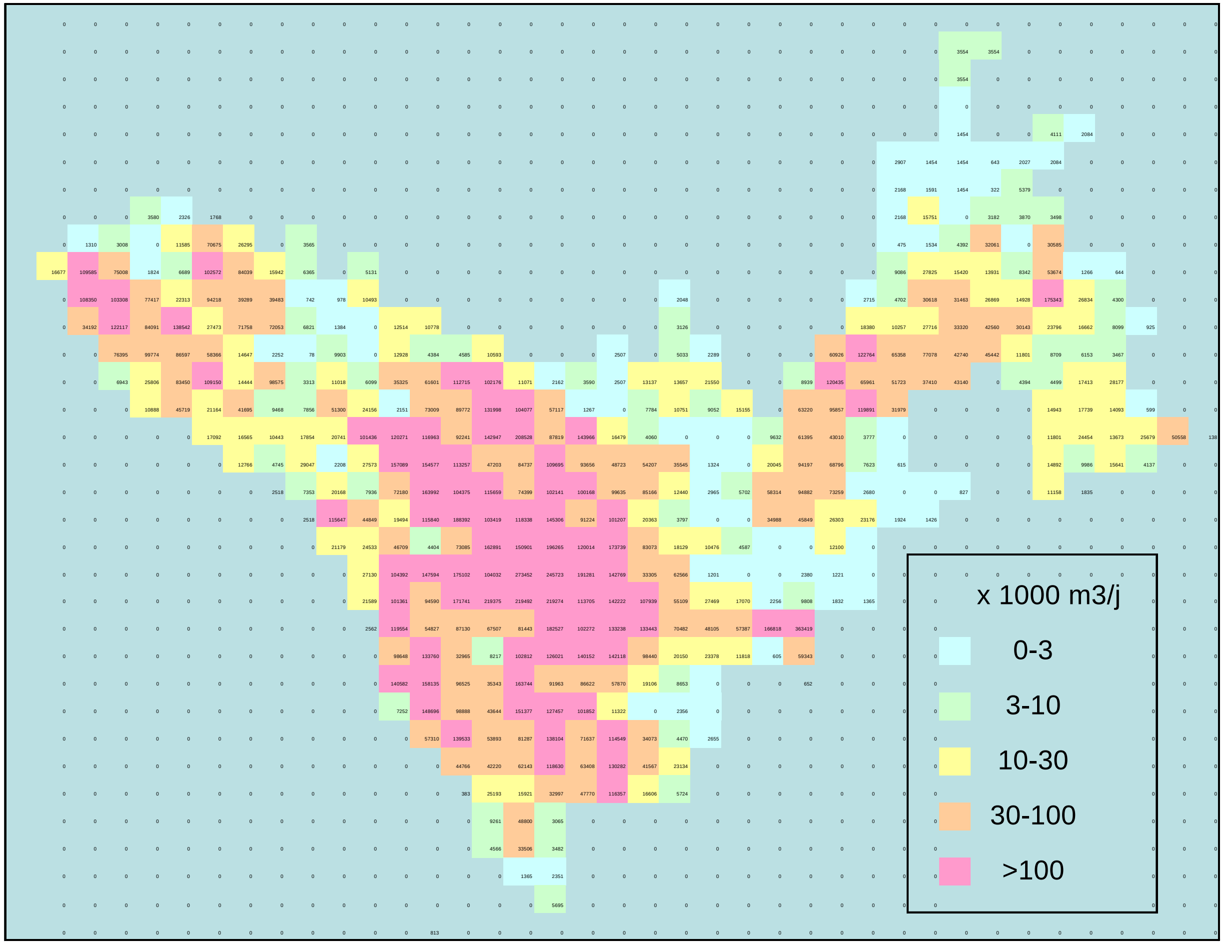
per supply category



total 26,0 Mm3/y

circa 142.000 connections

Supply in 2001 per grid 500 x 500 m2



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Water balance 26 March 2002