Inleiding watermanagement

Drinkwatertransport en -distributie

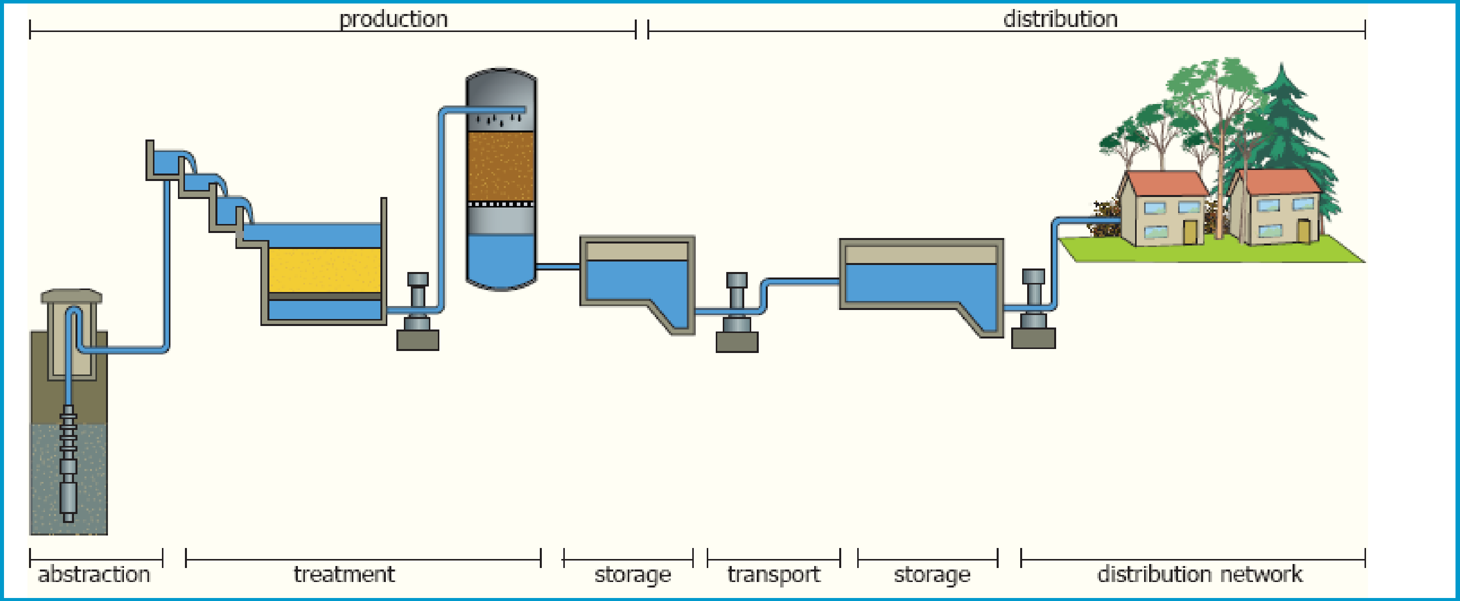
Prof. ir. Hans van Dijk

Technische Universiteit Delft

De Romeinse aquaducten

TU Delft

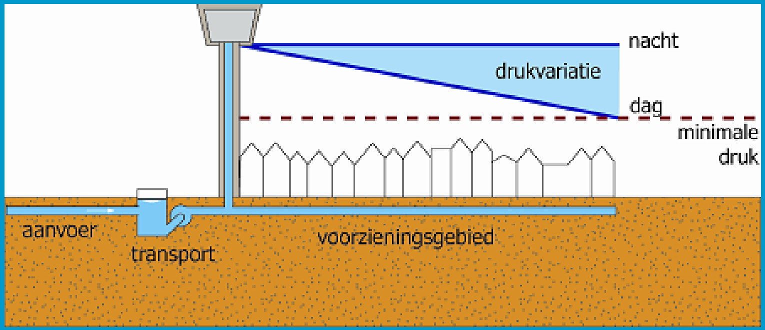
Drinkwater van tap tot bron

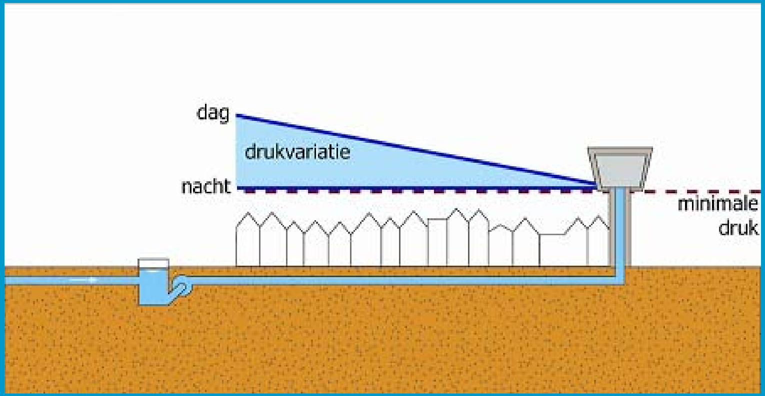


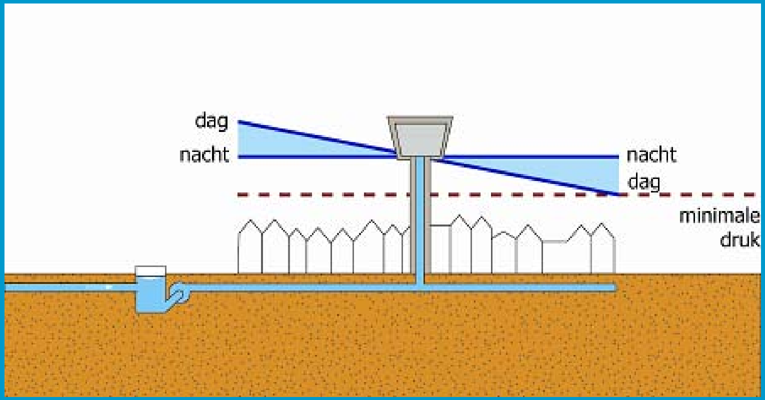
• Verbruik	afnemers, sterk fluctuerend, in voorzieningsgebied
• Distributie	levering aan meerdere afnemers, onder afleverdruk
• Opslag	uitvlakking tussen productie / transport en distributie
• Transport	gelijkmatige verplaatsing van water
• Productie	winning en zuivering, gelijkmatig

TU Delft

Druklijn in distributienet







TU Delft

Watertorens hielden net op druk

TU Delft

Druklijn bij torens en pompen

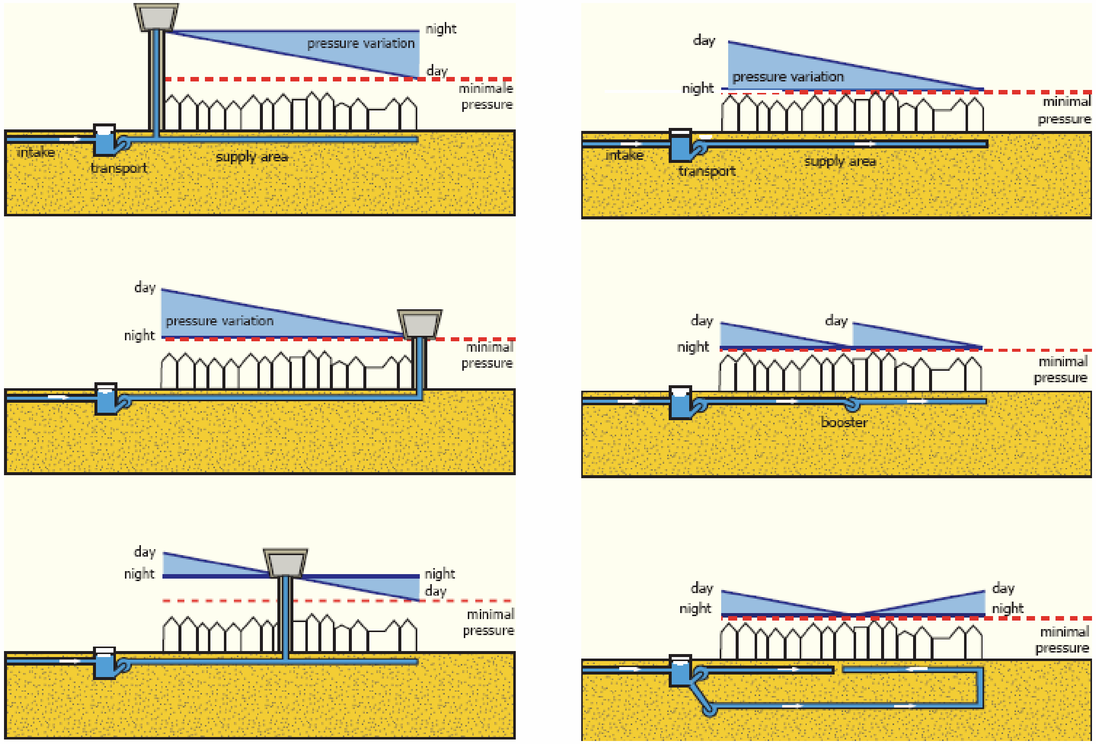
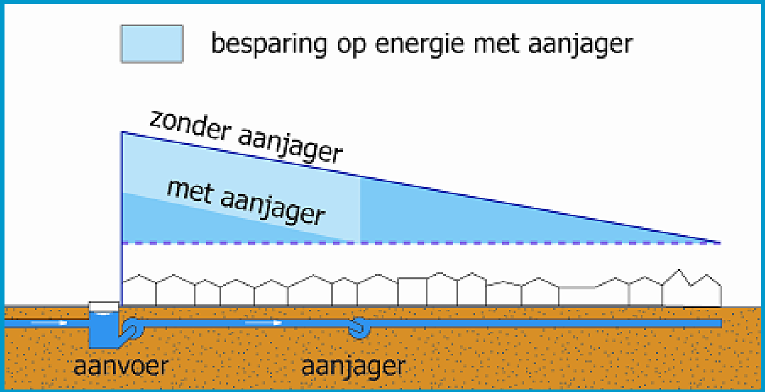
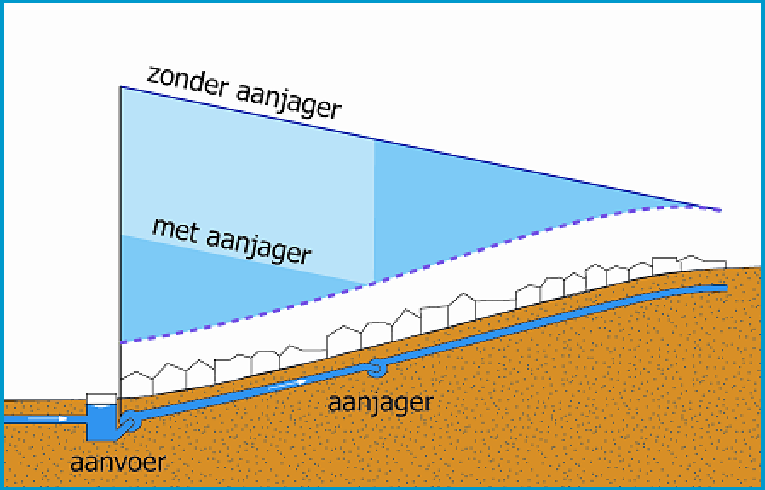
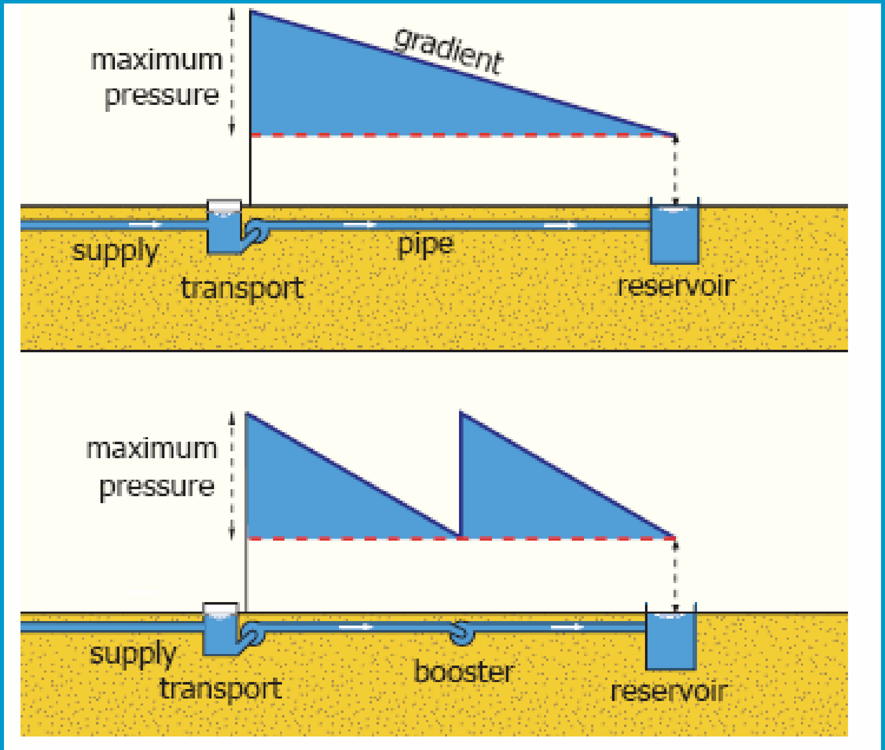


Figure 19 - Limitation of pressure fluctuation in a distribution network

Energiebesparing met boosters





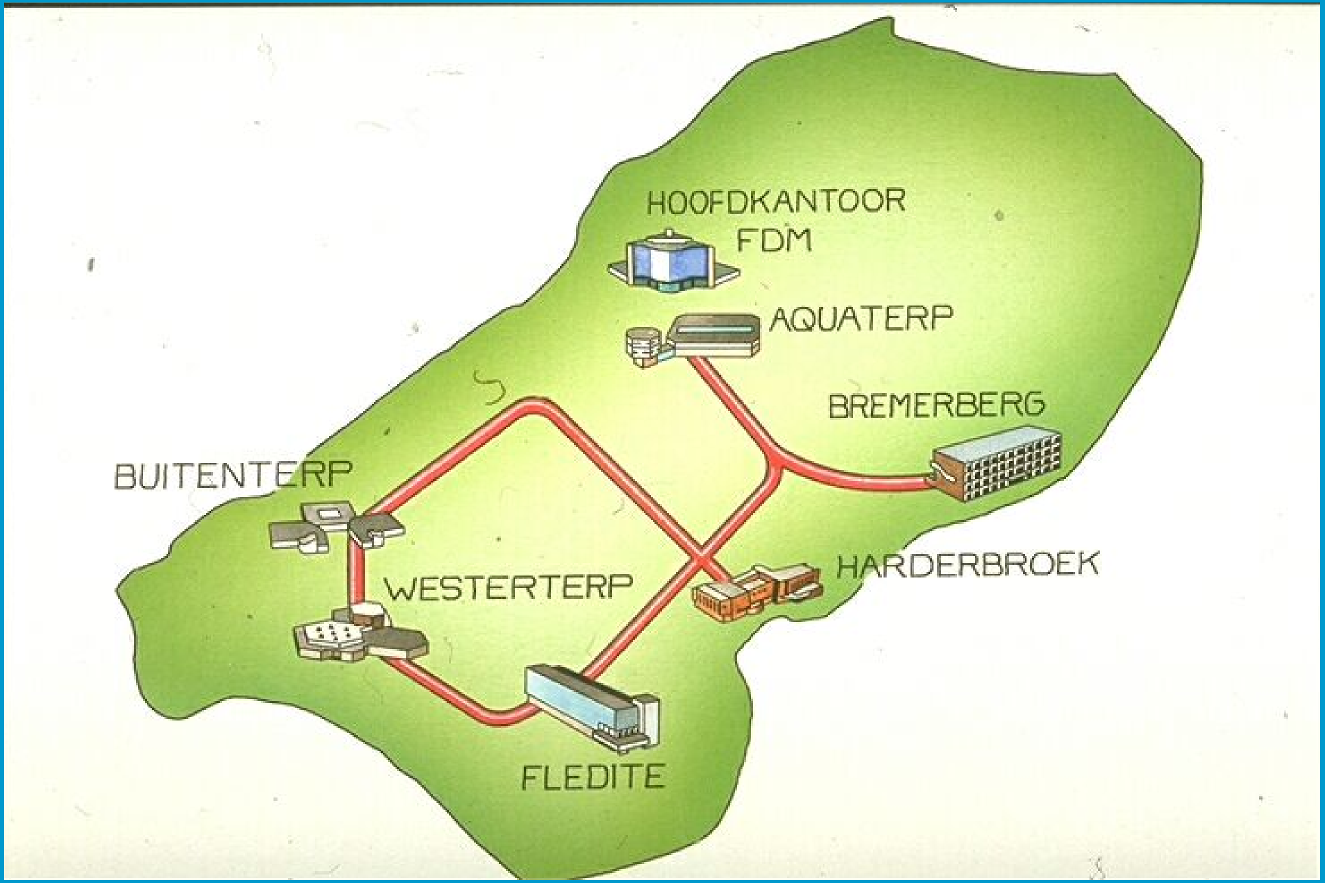


Opzet - Transport

Transport voor distributie

Watervoorziening
Flevoland

Transportnet
voor
Lelystad
en Almere



Transport - Hydraulica

Stromingsverliezen in leidingen :

wrijvingsverliezen

- eenparige stroming (weerstand aan de wand)

vertragingsverliezen

- onvolledige terugwinning snelheidshoogte

Transport - Hydraulica

Wrijvingverliezen

Darcy-Weisbach
$$\Delta H_w = \lambda \cdot \frac{L}{D} \cdot \frac{v^2}{2 \, . \, g}$$

Colebrook-White
$$\frac{1}{\sqrt{\lambda}} = -2 \cdot {}^{10}\log\left(\frac{k}{3{,}7 \, . \, D} + \frac{2{,}51}{Re\sqrt{\lambda}}\right)$$

$$Re = \frac{v.D}{\nu} \quad > \quad 4.000$$

waarin :

ΔH_w = weerstandverlies [m]

λ = weerstandscoëfficiënt [-]

L = lengte van de leiding [m]

D = diameter van de leiding [m]

v = snelheid in de leiding [m/s]

g = gravitatie-constante = 9.81 [m²/s]

k = wandruwheid [mm]

Re = Reynolds getal

ν = kinematische viscositeit [m²/s]

Transport - Hydraulica

Wandruwheid

Materiaal soort	k-waarde (mm)
metselwerk	1,0 - 5,0
beton	0,5 - 2,0
kunststof	0,01 - 0,05

Door veroudering (corrosie, afzettingen, slijmvorming) kan wandruwheid sterk toenemen (tot k-waarden van 10 mm)

Stromingstype

Meestal hydraulisch ruw (2^e term in log-deel formule verwaarloosbaar)

Weerstandscoëfficiënt

λ = 0,01 - 0,04 (veelal 0,02-0,03)

Veroudering kan resulteren in toename λ van 100% en meer

TU Delft

Transport - Hydraulica

Voorbeeld berekening wrijvingsverlies

- debiet = 10.000 m^3/h = 2,78 m^3/s
- transportafstand = 54 km = 54.000 m
- diameter buis = 1.500 mm = 1,5 m
- wandruwheid = 1,0 mm= 1,5 . 10^{-3} m

$$v = \frac{Q}{A} = \frac{Q}{\pi D^2/4} = \frac{2{,}78}{3{,}14 . 1{,}5^2/4} = \frac{2{,}78}{1{,}77} = 1{,}57\, m/s$$

$$Re = \frac{v . D}{\nu} = \frac{1{,}57 . 1{,}5}{1{,}0.10^{-6}} = 2{,}36.10^6$$

$$\frac{1}{\sqrt{\lambda}} = -2 \cdot {}^{10}\log\left(\frac{k}{3{,}7 . D} + \frac{2{,}51}{Re\sqrt{\lambda}}\right) = -2 \cdot {}^{10}\log\left(\frac{0{,}001}{3{,}7 . 1{,}5} + \frac{2{,}51}{2{,}36 . 10^6\sqrt{\lambda}}\right)$$

$$\text{iteratief}: \lambda = 0{,}0180 \quad (\text{zonder Re term}: \lambda = 0{,}0178)$$

$$\Delta H_w = \lambda \cdot \frac{L}{D} \cdot \frac{v^2}{2 . g} = 0{,}0180 \frac{54000}{1{,}5} \cdot \frac{1{,}57^2}{2 . 9{,}81} = 81{,}4\, m$$

TU Delft

Transport - Hydraulica

Vertragingsverliezen

- bochten en knikken

$$\Delta H_v = \xi \cdot \frac{v^2}{2 \cdot g} = (A \cdot B) \cdot \frac{v^2}{2 \cdot g}$$

- vernauwing en verwijding

$$\Delta H_{v,u} = \xi_{verwijding} \cdot \frac{v^2}{2 \cdot g}$$

$$\xi_{verwijding} = \left(1 - \frac{A_1}{A_2}\right)^2$$

- in- en uittredeverlies

$$\Delta H_{v,i} = \xi_{intrede} \cdot \frac{v^2}{2 \cdot g}$$

$\xi_{intrede} = 0{,}5$ na insnoering

$$\Delta H_{v,u} = \xi_{uittrede} \cdot \frac{v^2}{2 \cdot g}$$

$\xi_{uittrede} = 1{,}0$

Transport - Hydraulica

Vertragingsverliezen

- terugslagkleppen $\xi = 2{,}5$

- afsluiters $\xi = 0{,}2 - 0{,}5$

Berekening vertragingsverliezen leidingsegment :

$$\Delta H_v = \sum \xi \cdot \left(\frac{v^2}{2 \cdot g} \right)$$

Praktijk ξ totaal = 1 - 4 (korte leidingen), 2 - 50 (lange leidingen)

Transport - Hydraulica

Voorbeeld berekening vertragingsverlies

- debiet = 10.000 m^3/h
- transportafstand = 54 km
- diameter buis = 1.500 mm
- aantal bochten = 30 (ξ = 0,5 gemidd. per bocht)
- aantal afsluiters = 10 (ξ = 0,3 gemidd. per afsluiter)
- terugslagklep = 1 (ξ = 2,5)
- in+uitstroming = 1 (ξ = 1,5 totaal)

$$\mathrm{v} = \frac{\mathrm{Q}}{\mathrm{A}} = \frac{\mathrm{Q}}{\pi\,\mathrm{D}^2/4} = \frac{2{,}78}{3{,}14\,.1{,}5^2/4} = \frac{2{,}78}{1{,}77} = 1{,}57\, m/s$$

$$\Delta\mathrm{H}_\mathrm{v} = (30\times 0{,}5 + 10\times 0{,}3 + 2{,}5 + 1{,}5)\cdot\frac{1{,}57^2}{2\cdot 9{,}81} = 22\cdot\frac{1{,}57^2}{2\cdot 9{,}81} = 2{,}8 \quad m$$

Transport - Hydraulica

Totaal stromingsverliezen:

wrijvingsverlies

$$\Delta H_w = \lambda \cdot \frac{L}{D} \cdot \frac{v^2}{2 \cdot g}$$

vertragingsverliezen

$$\Delta H_v = \sum \xi \cdot \frac{v^2}{2 \cdot g}$$

Bij lange leidingen (L / D > 500) zijn vertragingsverliezen verwaarloosbaar

Bij korte leidingen (L / D < 10) zijn wrijvingsverliezen verwaarloosbaar

Totaal stromingverlies

$$\Delta H = c_w \,.\, Q^2 + c_v \,.\, Q^2$$

c_w afhankelijk van D, L, k en ν

c_v afhankelijk van D en $\Sigma\xi$

TU Delft

Transport – Economische diameter

Aanlegkosten $K_{aanleg} = 500 \cdot D \cdot L$

Energiekosten $P = QH\rho g/\eta$, $E = Pt$

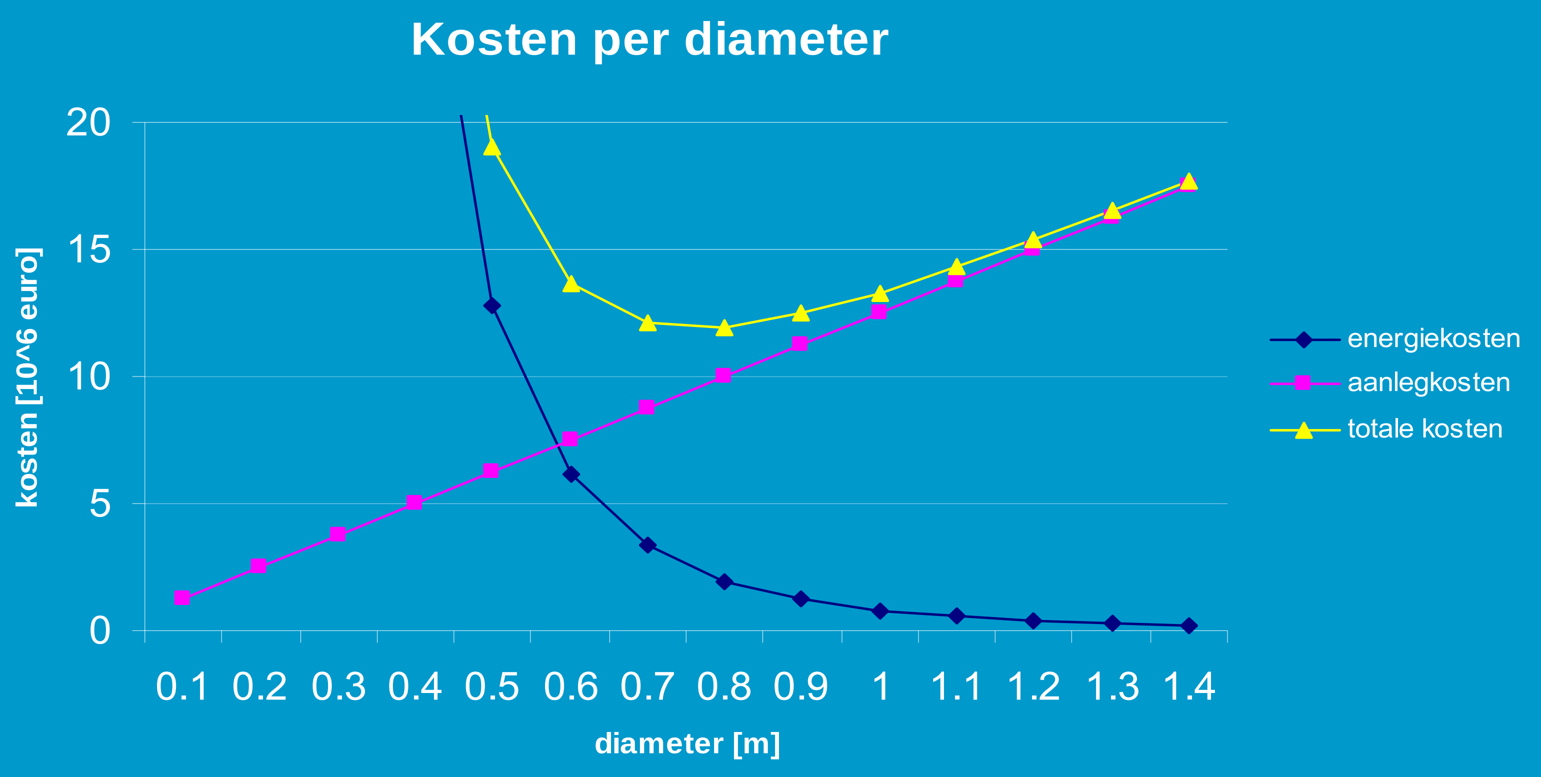
$H = \lambda L/D v^2/2g = 0{,}02 L Q^2/2gD^5$

- per jaar $K_{energie} = 16{,}7 \cdot Q^3 \cdot D^{-5} \cdot L$
- over 50 jaar $K_{energie} = 19{,}2 \cdot 16{,}7 \cdot Q^3 \cdot D^{-5} \cdot L$

Totale kosten $K_{totaal} = 19{,}2 \cdot 16{,}7 \cdot Q^3 \cdot D^{-5} \cdot L + 500 \cdot D \cdot L$

Transport - Economische diameter

Uitwerking van meest economische diameter:



Transport – Economische snelheid

Totale kosten

$$K_{totaal} = 16{,}7 \cdot Q^3 \cdot D^{-5} \cdot L + 500 \cdot D \cdot L$$

Minimale kosten als afgeleide 0 is

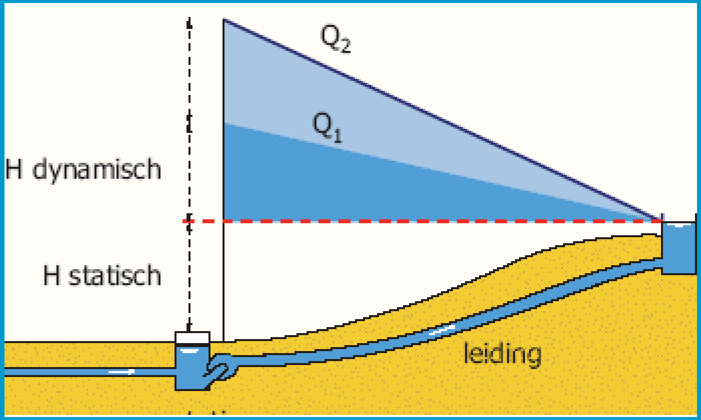
$$dK_{totaal}/dD = -5 \cdot 19{,}2 \cdot 16{,}7 \cdot Q^3 \cdot D^{-6} \cdot L + 500 \cdot L = 0$$

$$D = 1{,}2 \cdot \sqrt{Q}$$

$$v = \frac{Q}{A} = \frac{\left(\frac{D}{1.2}\right)^2}{0.25 \cdot \pi \cdot D^2} = 0.88 \text{ m/s}$$

Flow (mln m³/y)	Flow (m³/s)	Velocity (m/s)	Diameter (mm)	Gradient (m/km)
1	0.032	0.88	210	3.7
2	0.063	0.88	300	2.6
5	0.158	0.88	480	1.6
10	0.32	0.88	680	1.2
20	0.63	0.88	960	0.8
50	1.58	0.88	1,510	0.5
100	3.2	0.88	2,140	0.4

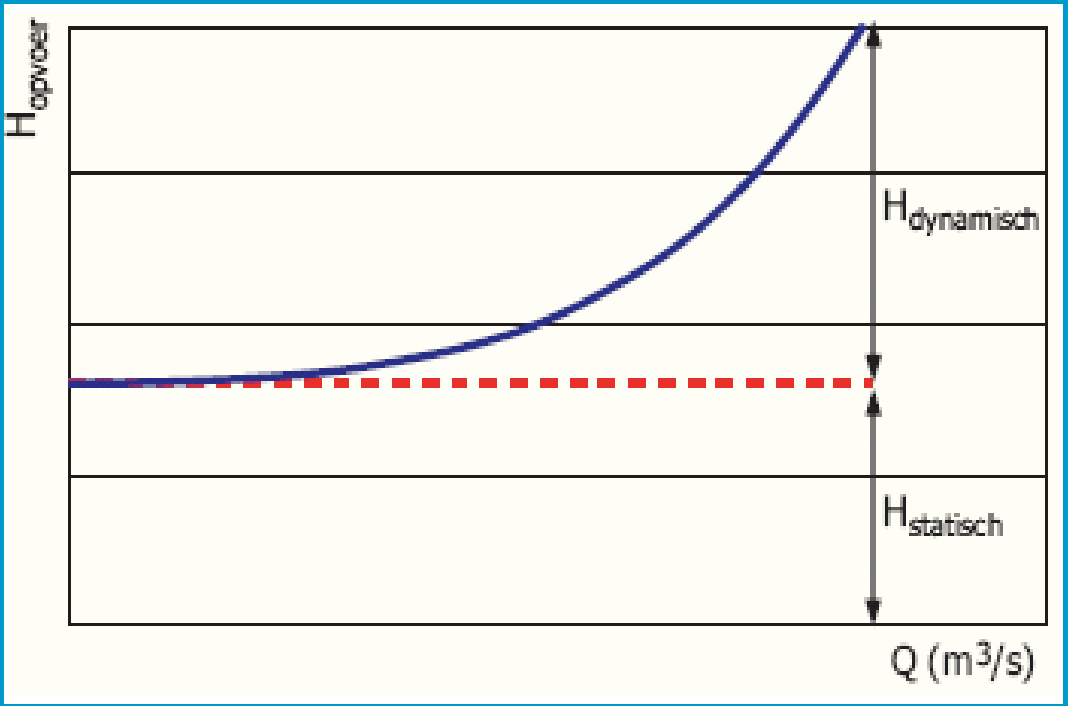
Statische en dynamische opvoerhoogte



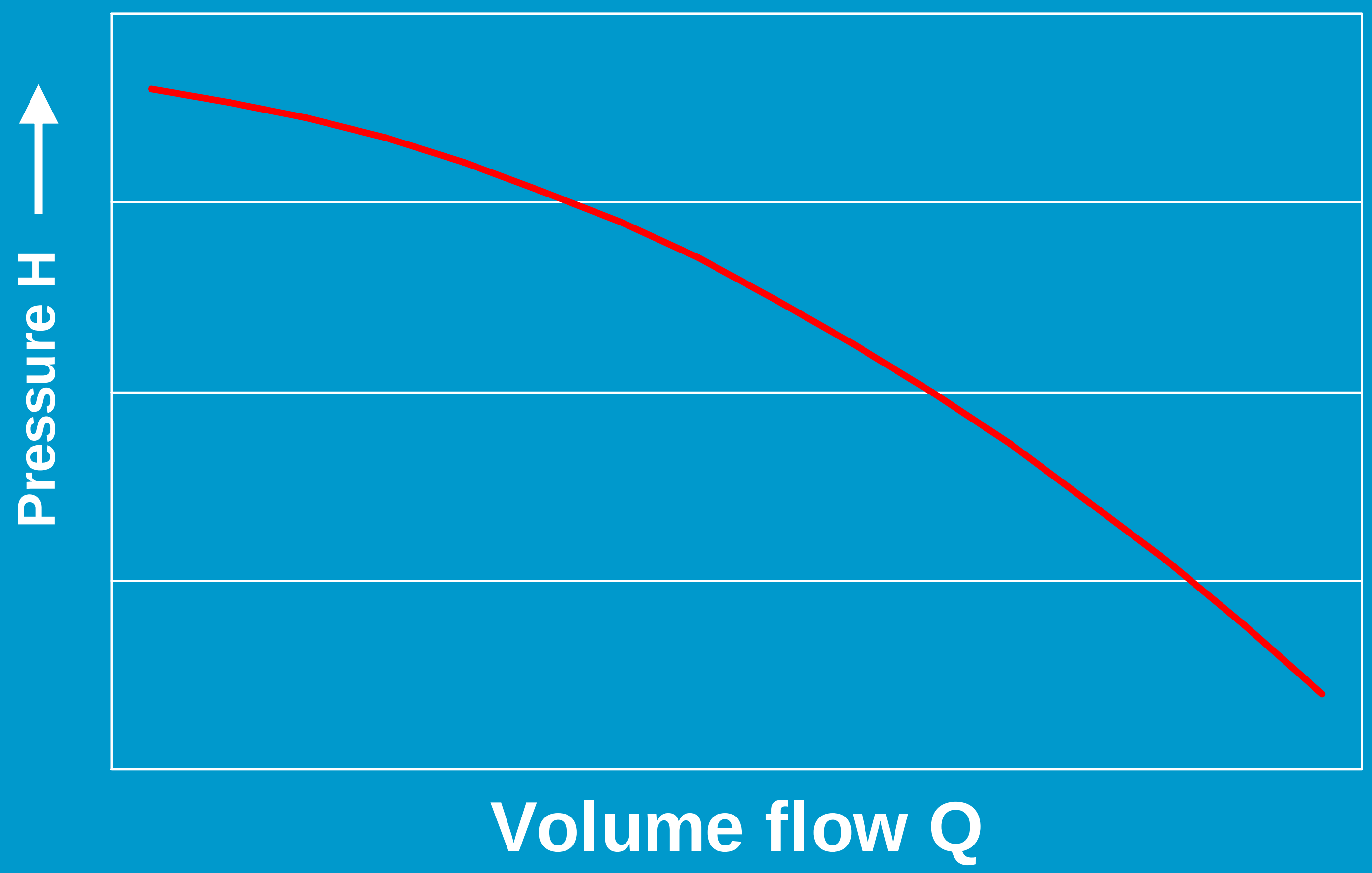
Leidingkarakteristiek

$$H = H_s + \Delta H_w + \Delta H_v = H_s + \lambda \cdot \frac{L}{D} \cdot \frac{u^2}{2 \cdot g} + \left(\sum \xi\right) \cdot \frac{u^2}{2 \cdot g}$$

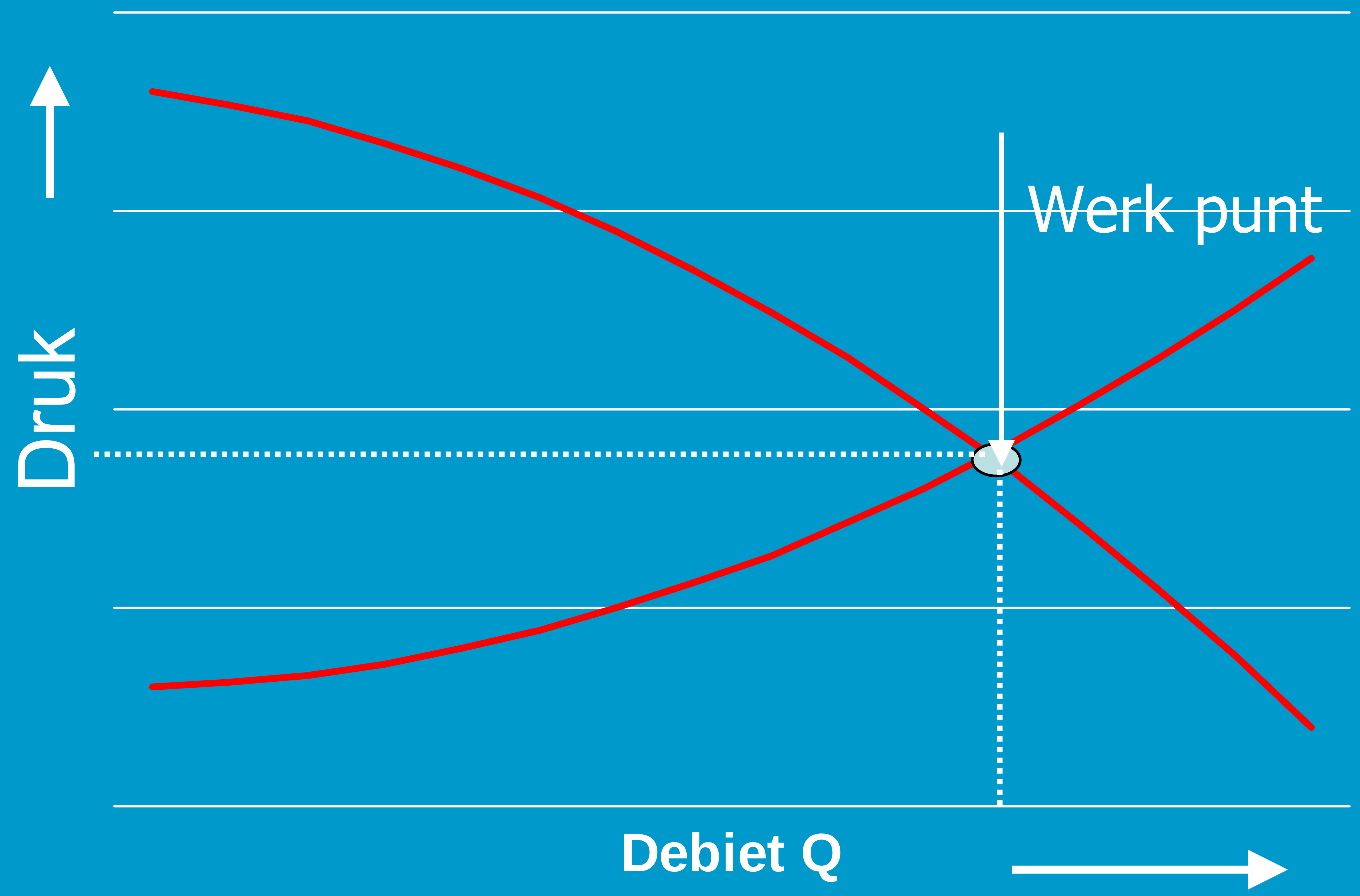
$$= H_s + c_1 \cdot Q^2 + c_2 \cdot Q^2$$



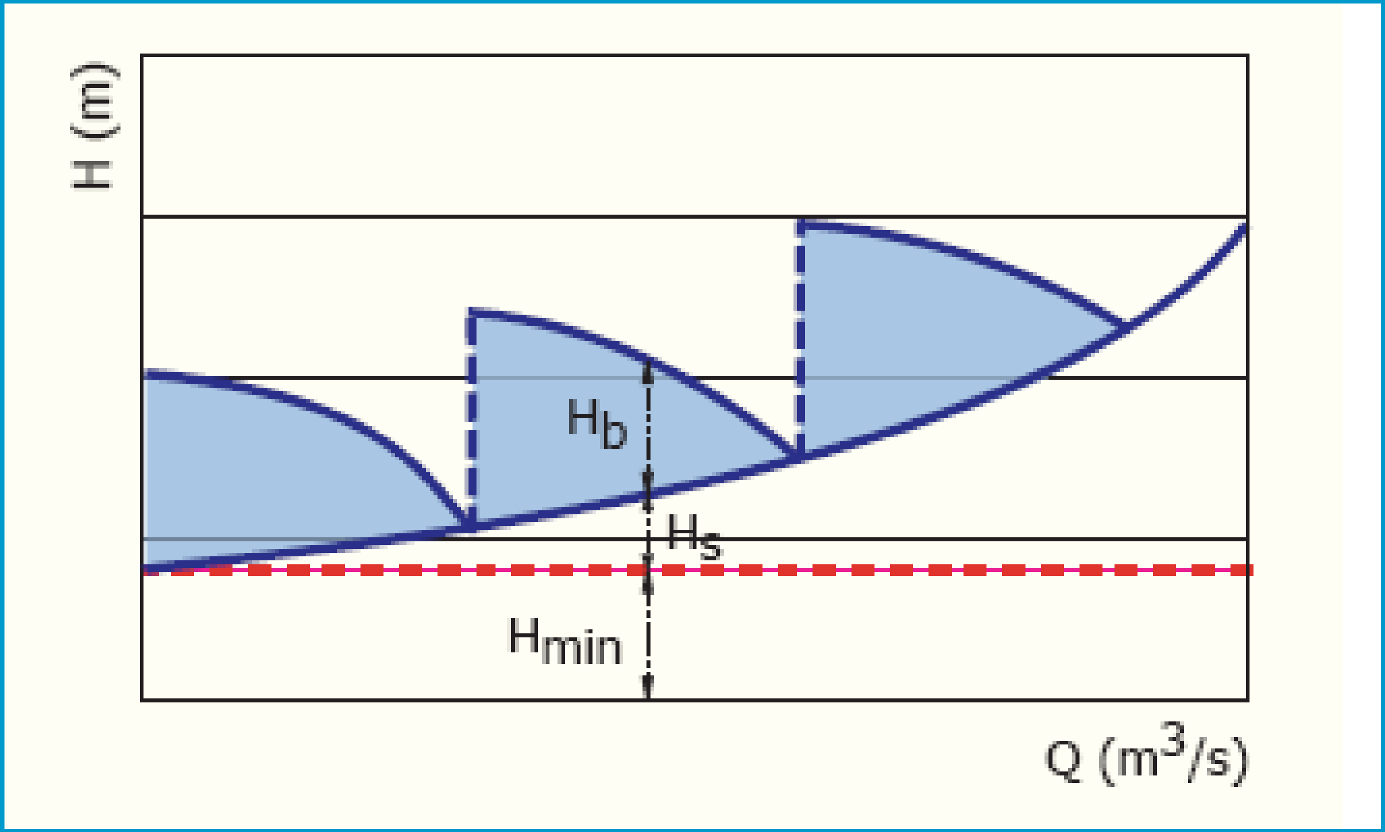
Q-H curve



Werkpunt



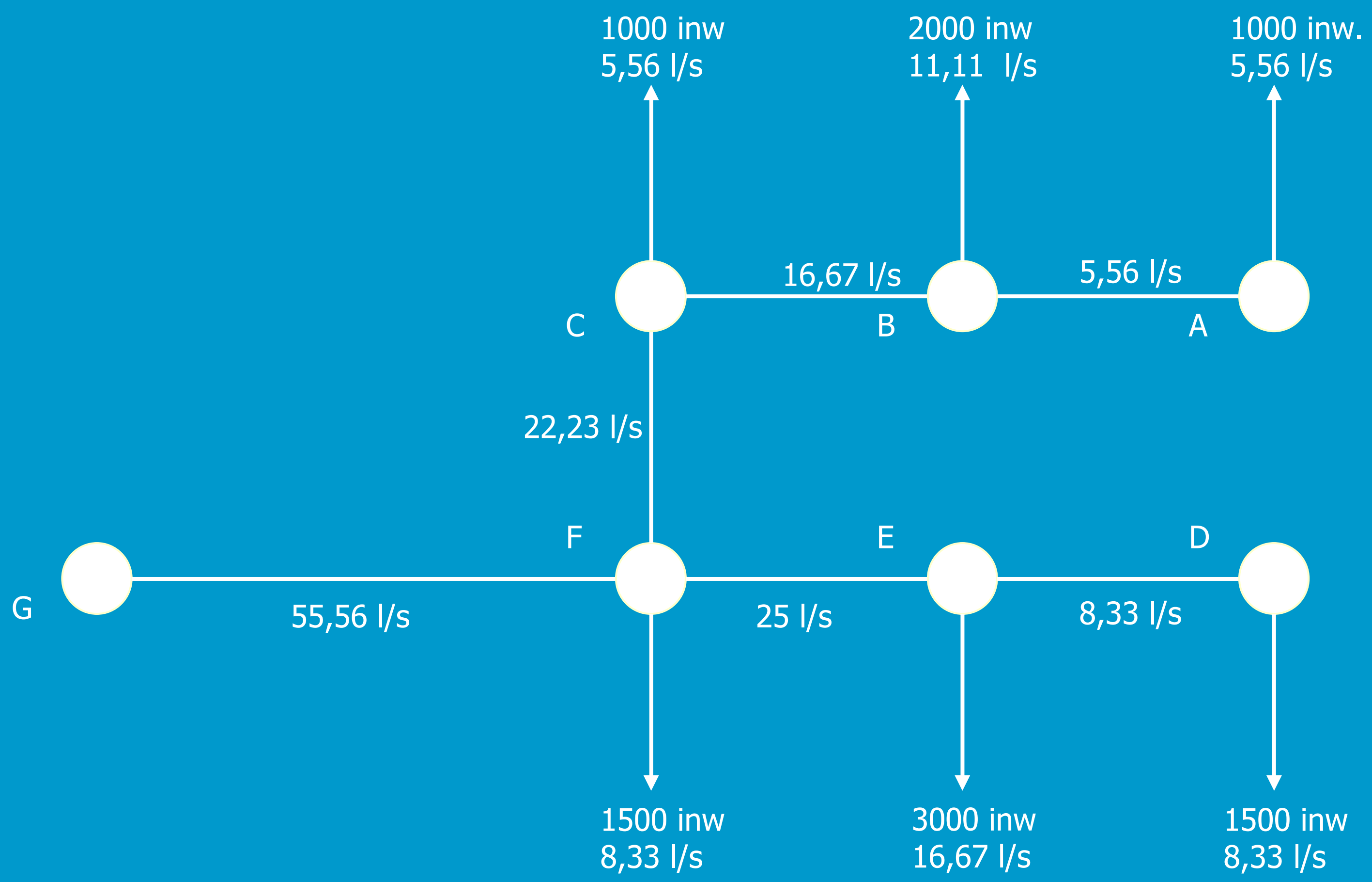
Pomp ontwerp



TU Delft

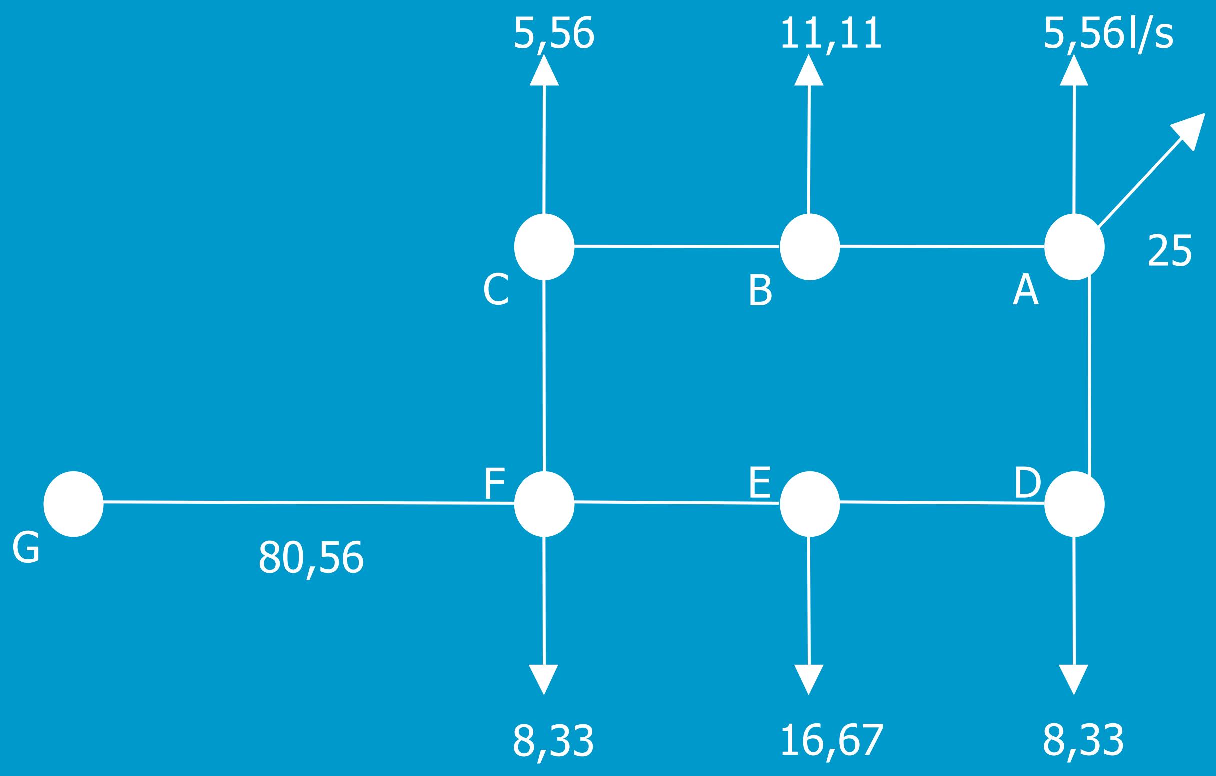
Pompstations

Vertakt net



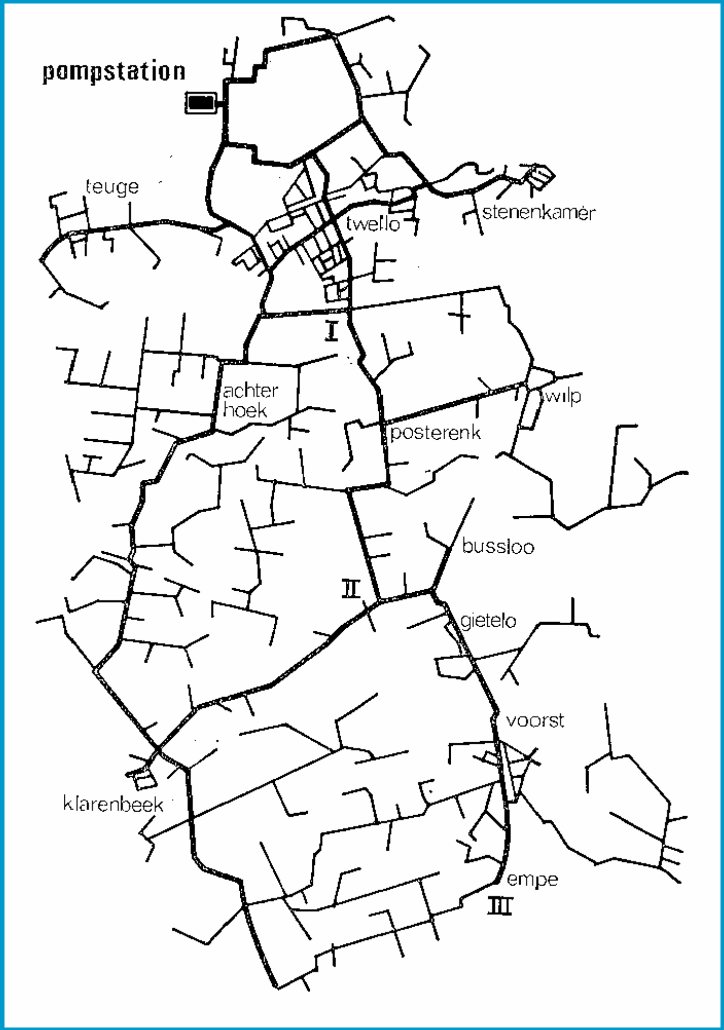
TUDelft

Vermaasd net



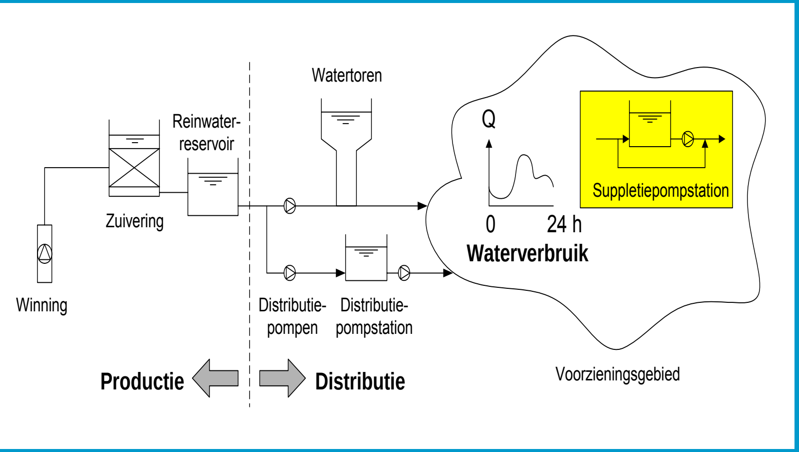
TU Delft

Praktijk net

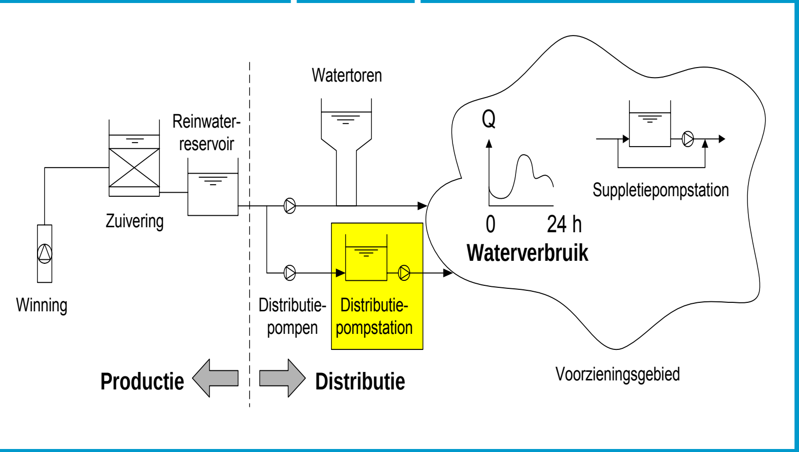


Distributie

Suppletiepompstation



Distributiepompstation

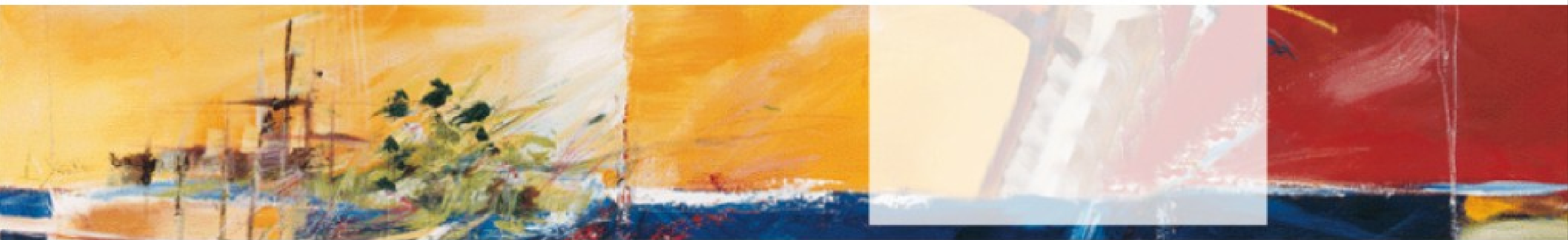


Jan Vreeburg

UNESCO-IHE Institute for Water Education

TU Delft Technische Universiteit Delft

kiwa Partner for progress



Discolouration: Who’s to blame

Delft Cluster

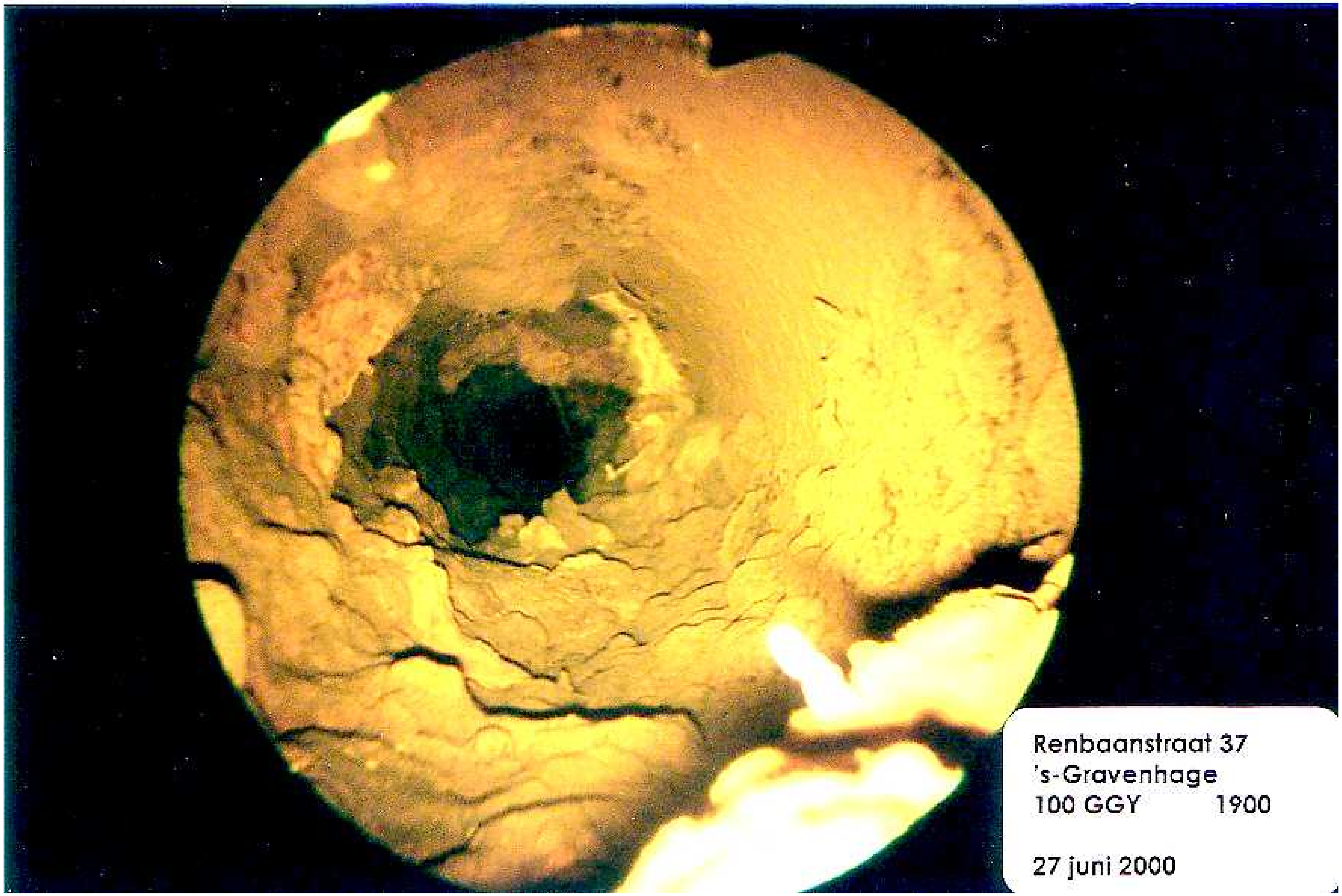
TECHNEAU

Q21

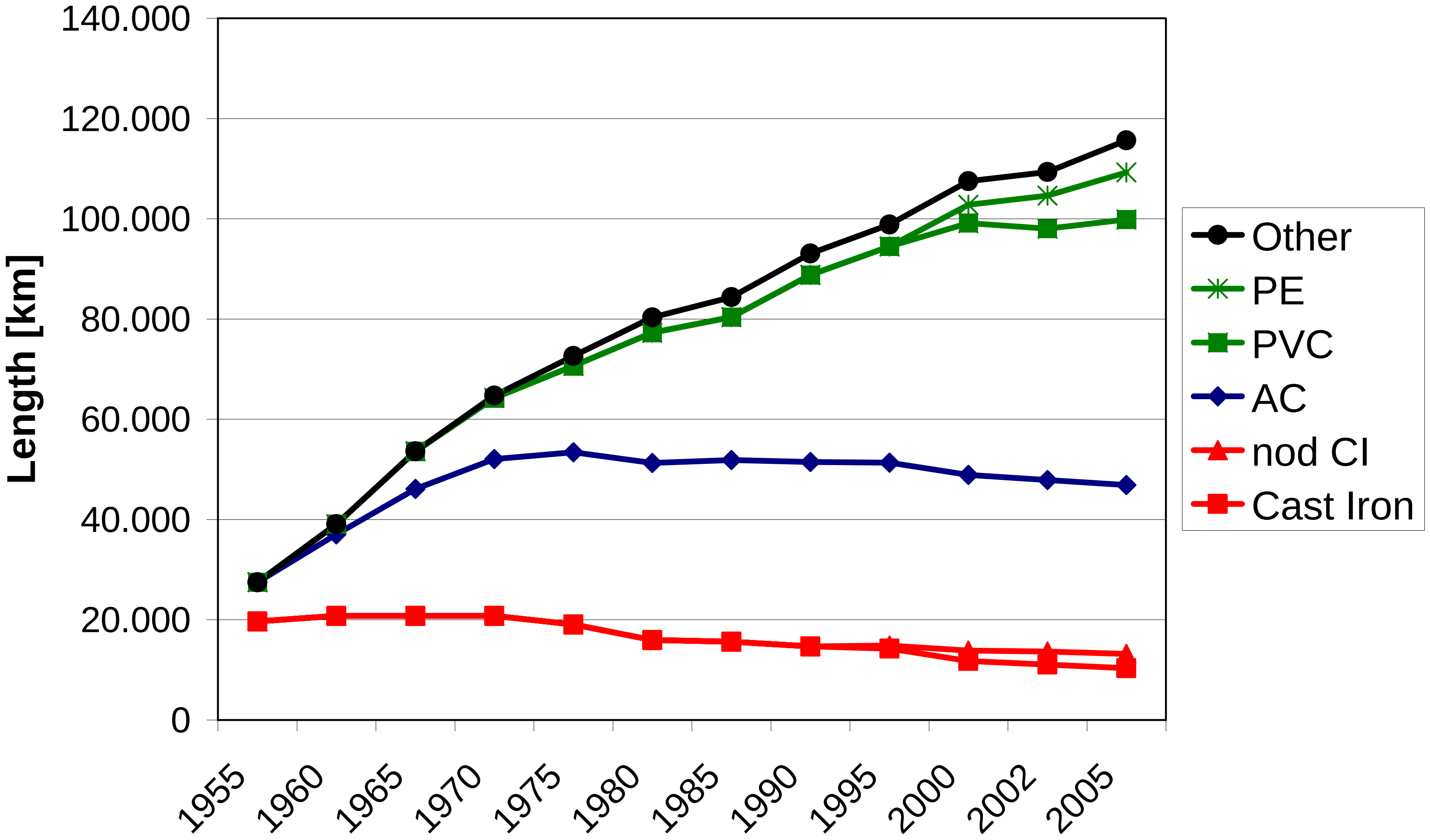
Beautiful stories on water treatment: but this comes out of the tap, even in the Netherlands

Drinking water distribution is a matter of skilled labour

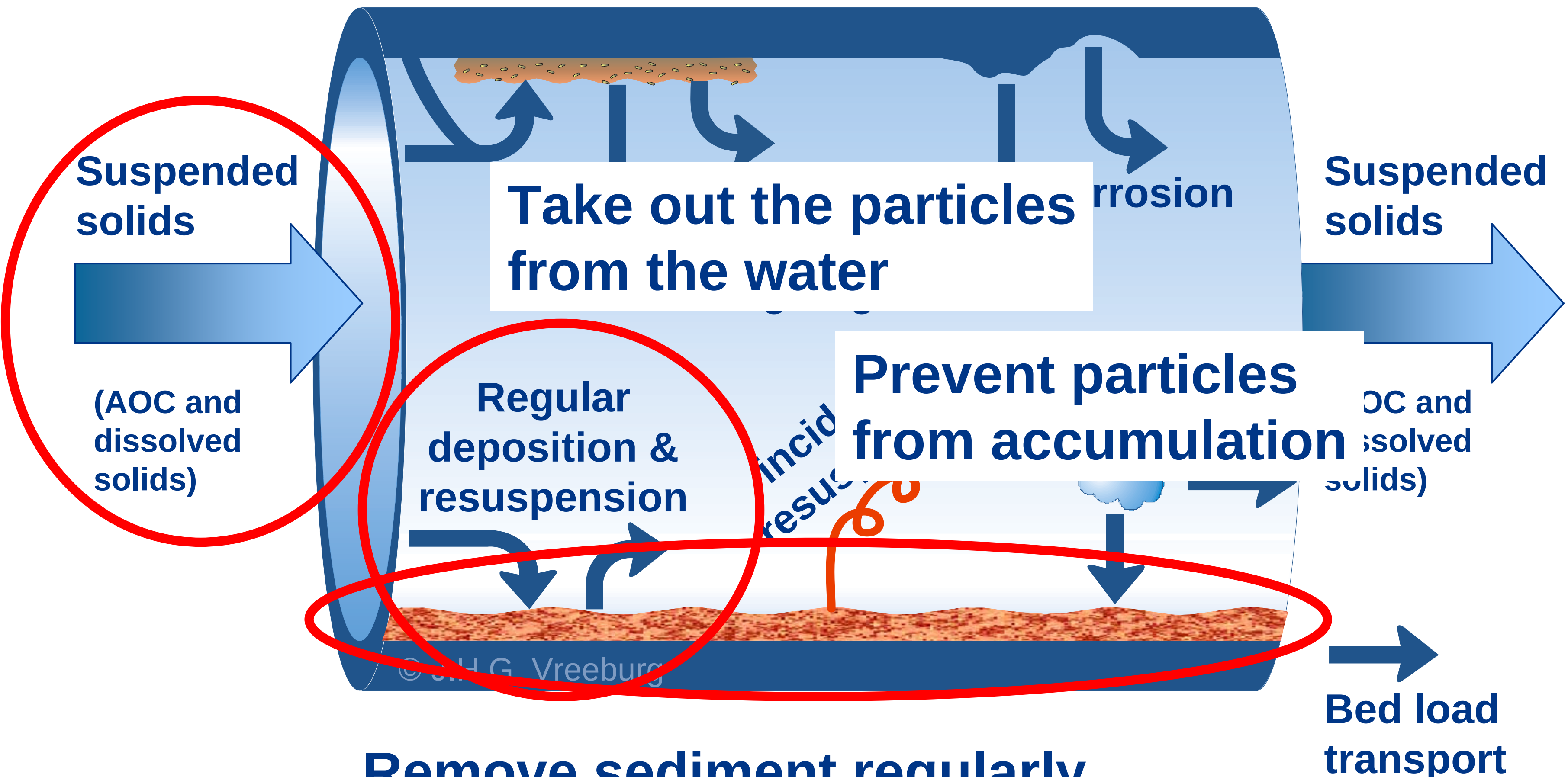
Cast iron: the classic cause of discolouration (Ø100 Cast Iron,1900)



But: there is so little cast iron and still 3000 to 6000 complaints

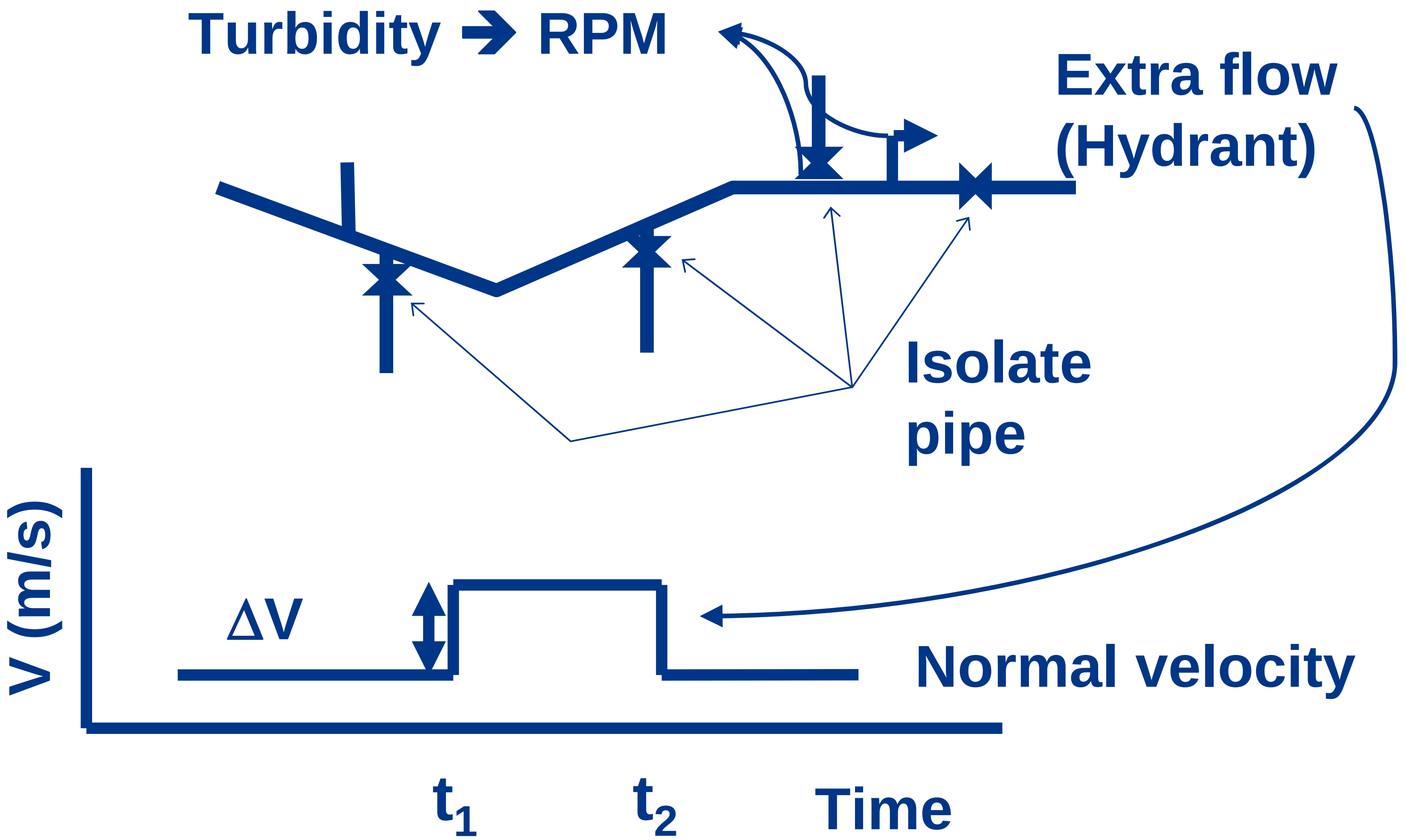


The complete picture:
Particle related processes in a network

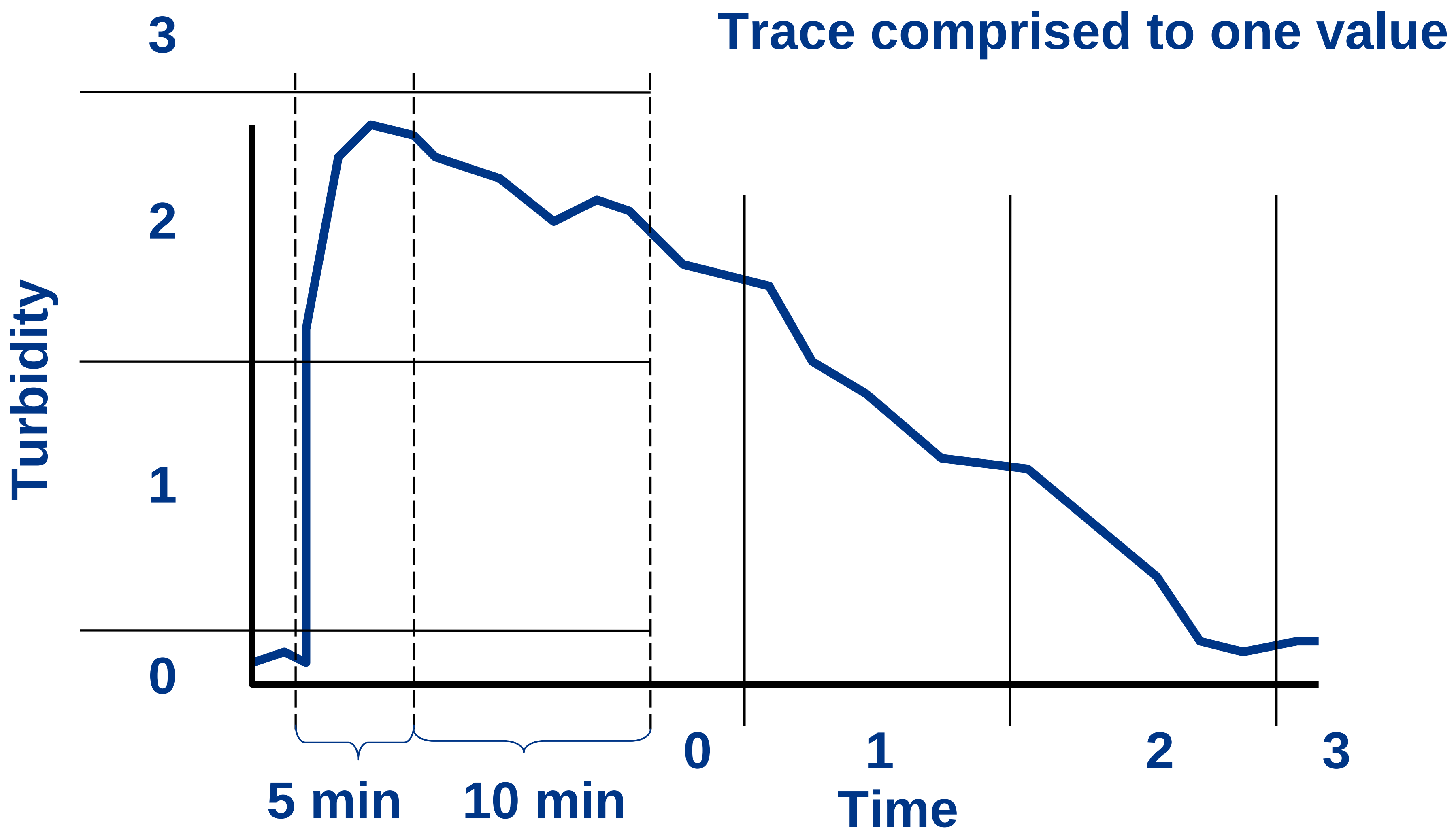


Remove sediment regularly

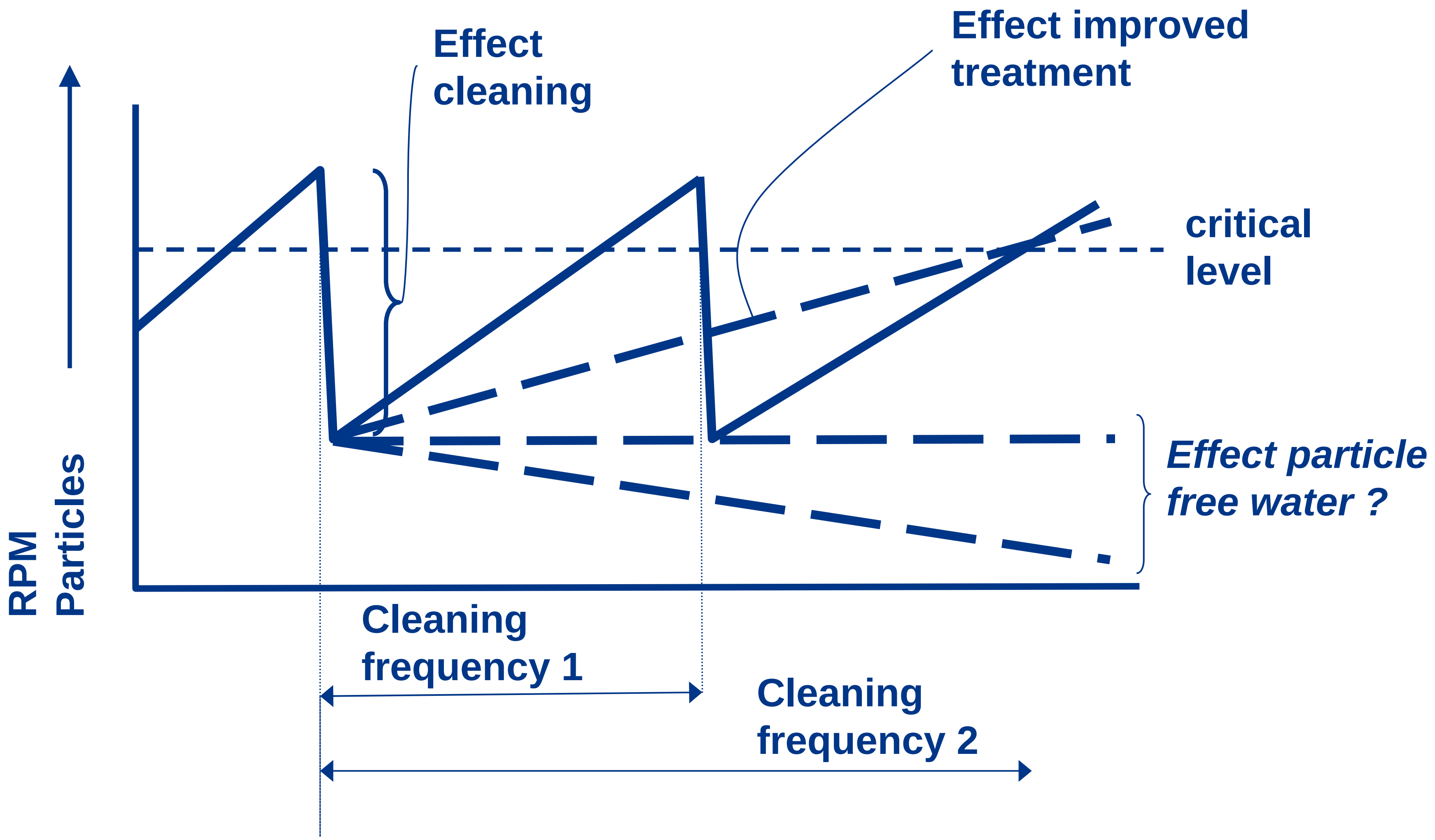
Measuring method to asses the discolouration risk: the Resuspention Potential Method



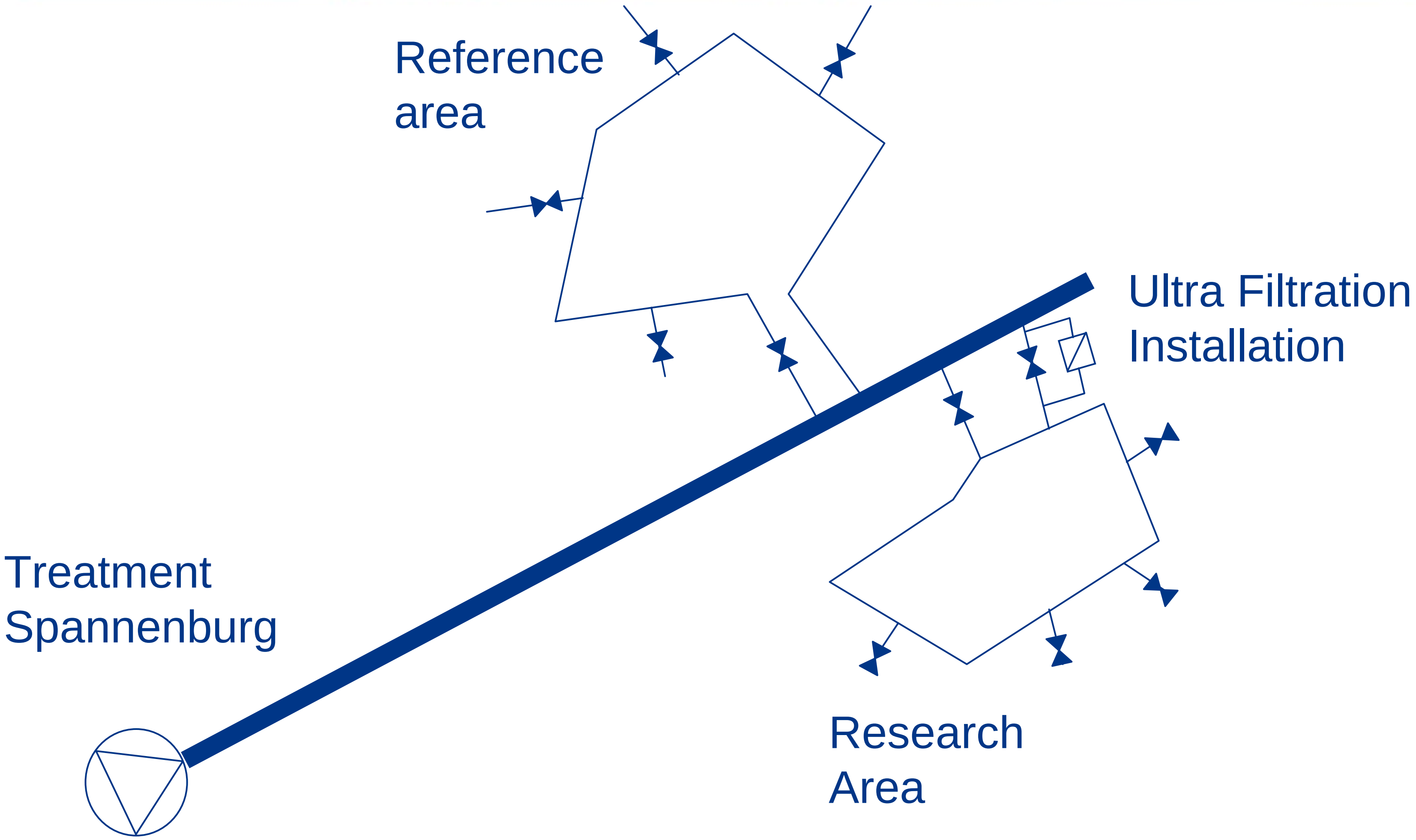
Validate RPM result



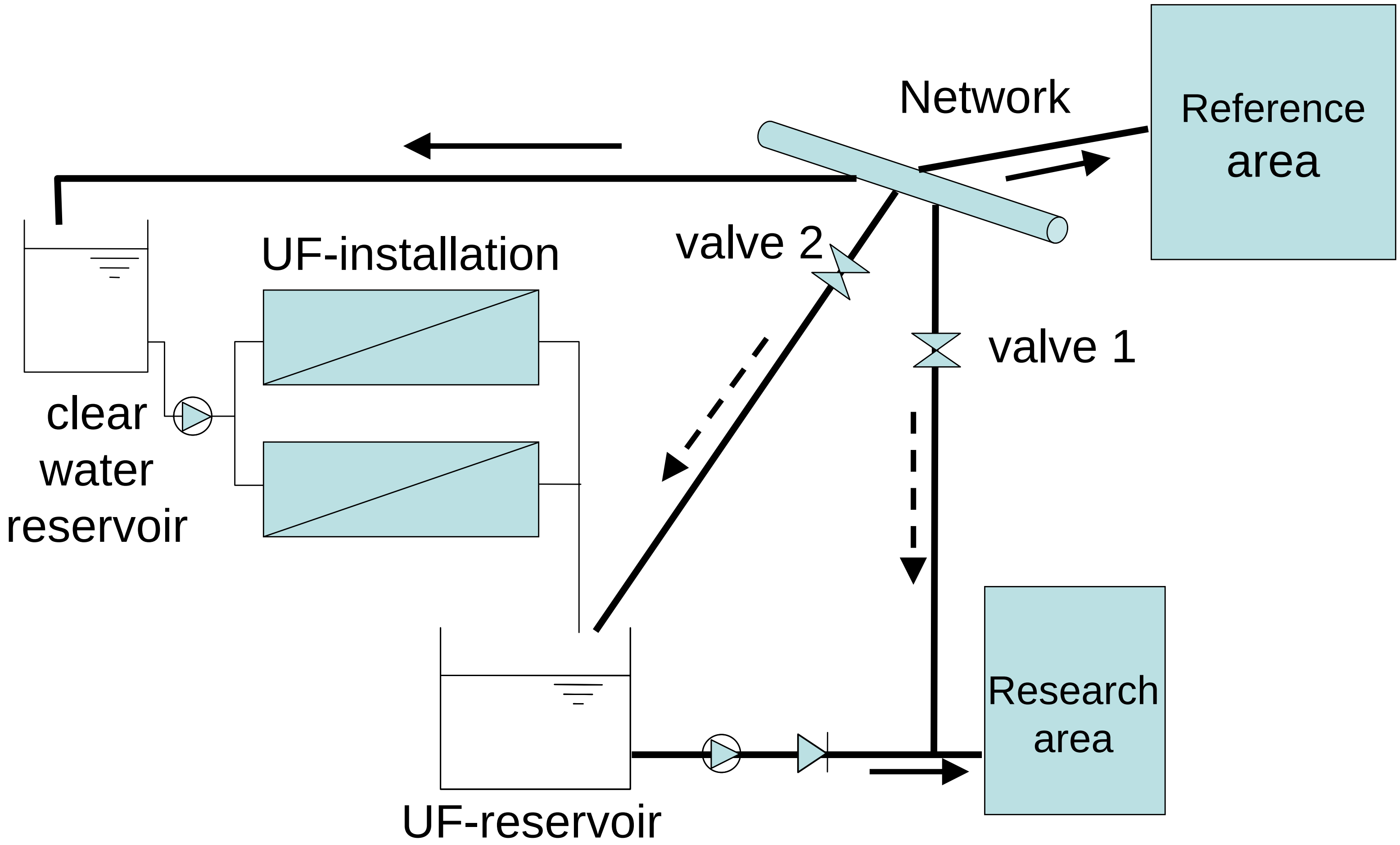
Hypothesis effect particle load from treatment



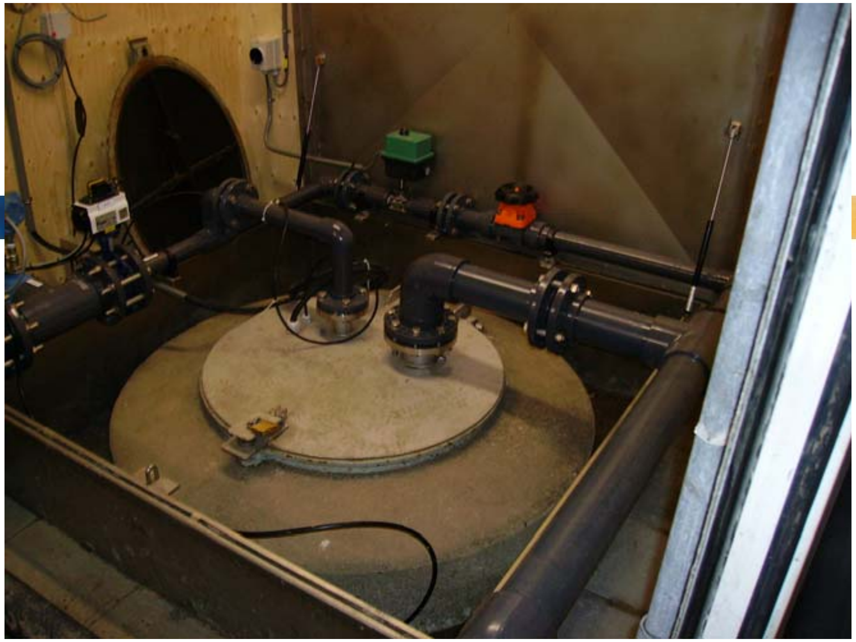
The experiment with particle free water



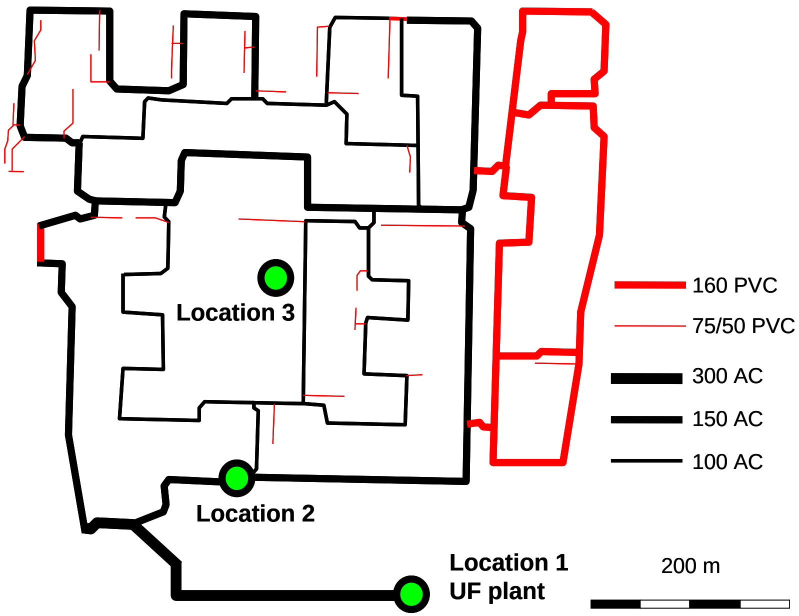
Detail connection research area

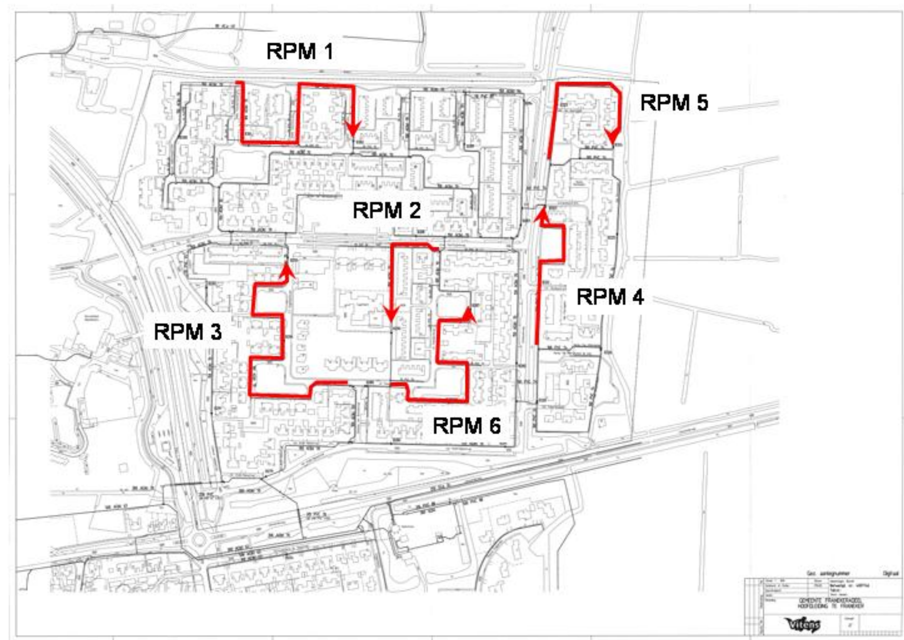


Location



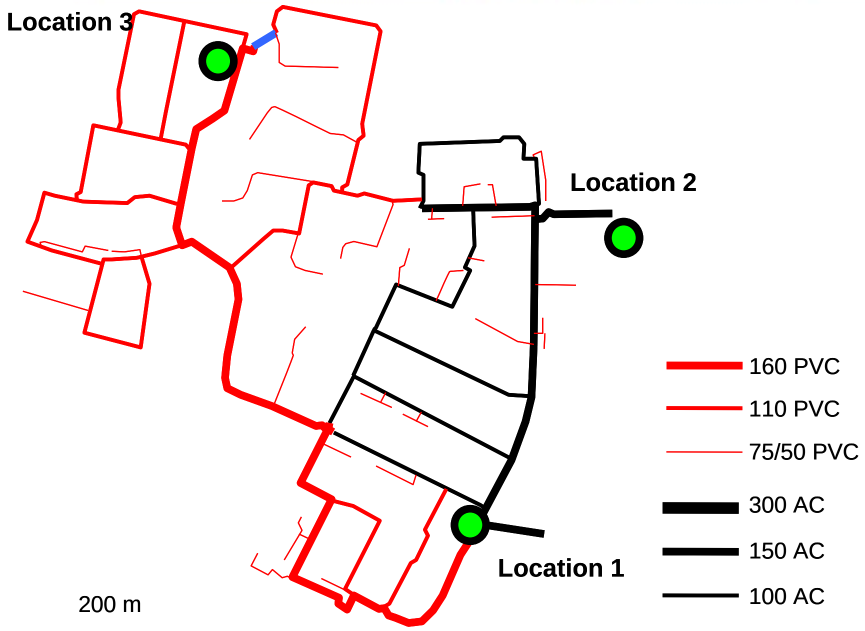
The Research area

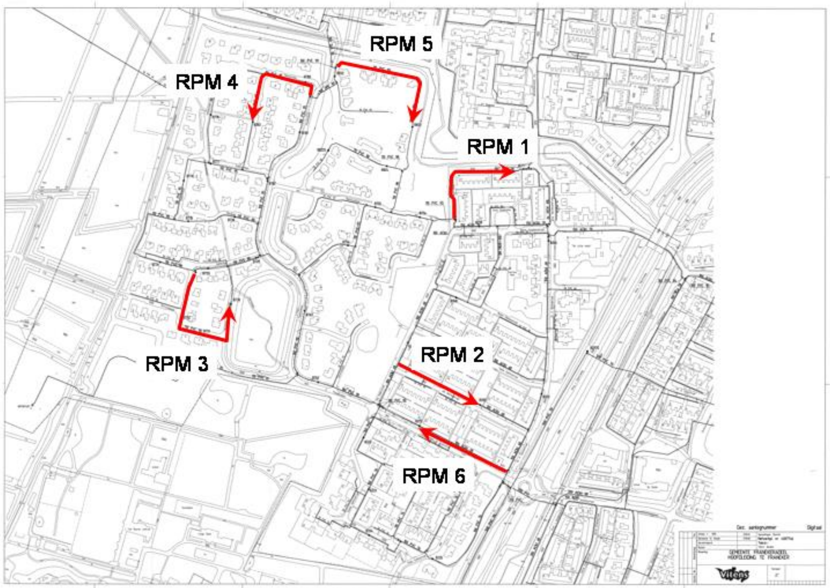




- **550 connections à 2,6 persons using 122 lppd (2004)**
- **1970 AC part; PVC part 1974**

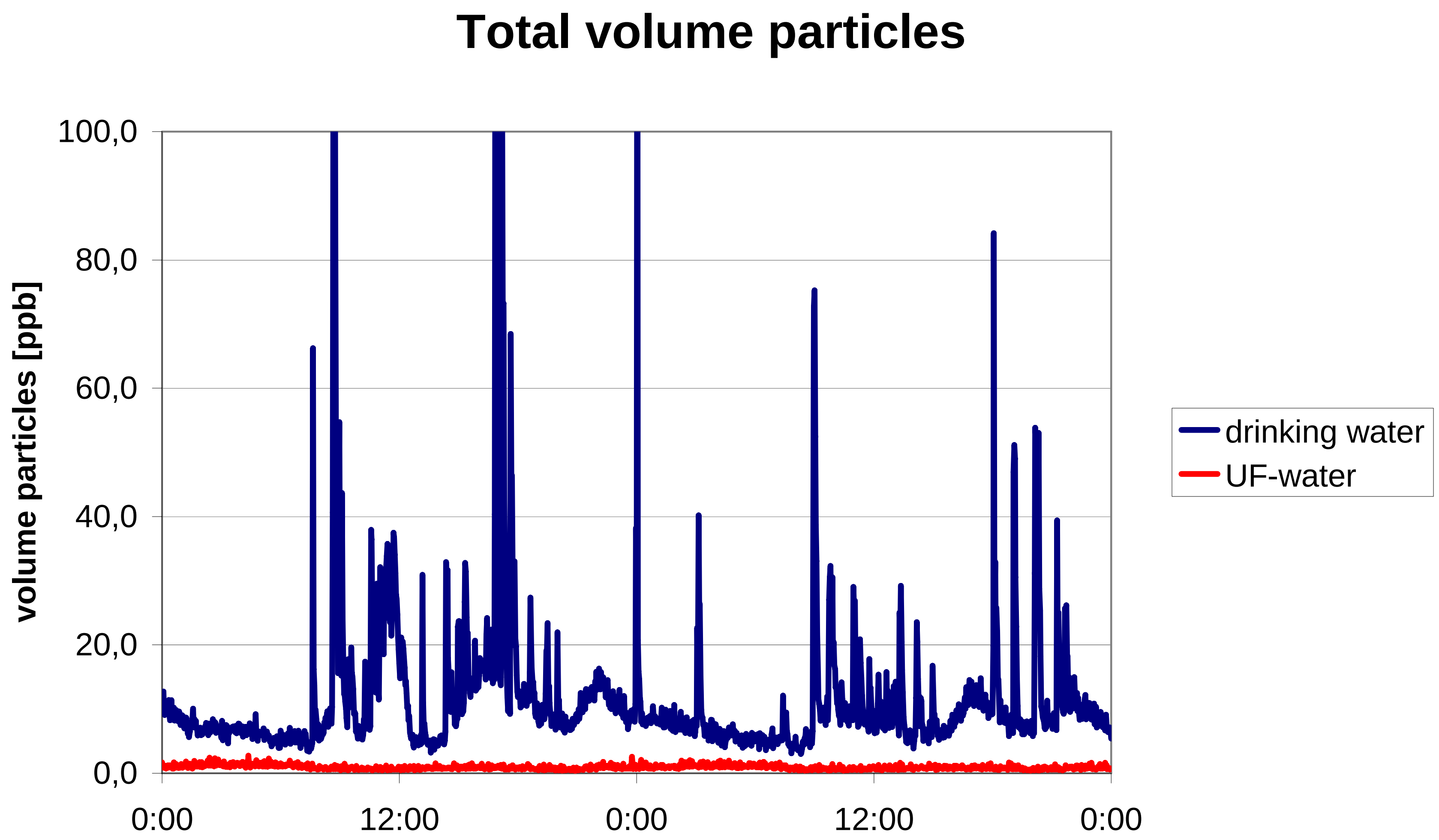
The Reference Area



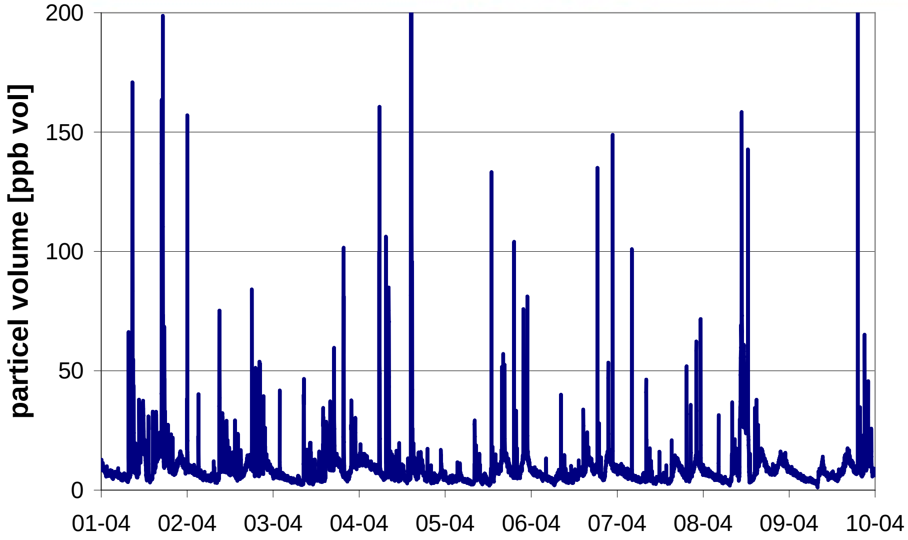


- 520 connections à 2,7 persons using 118 lppd (2004)
- 1968-1969 AC part; 1st PVC part 1974;
  2nd PVC part 1995-1999

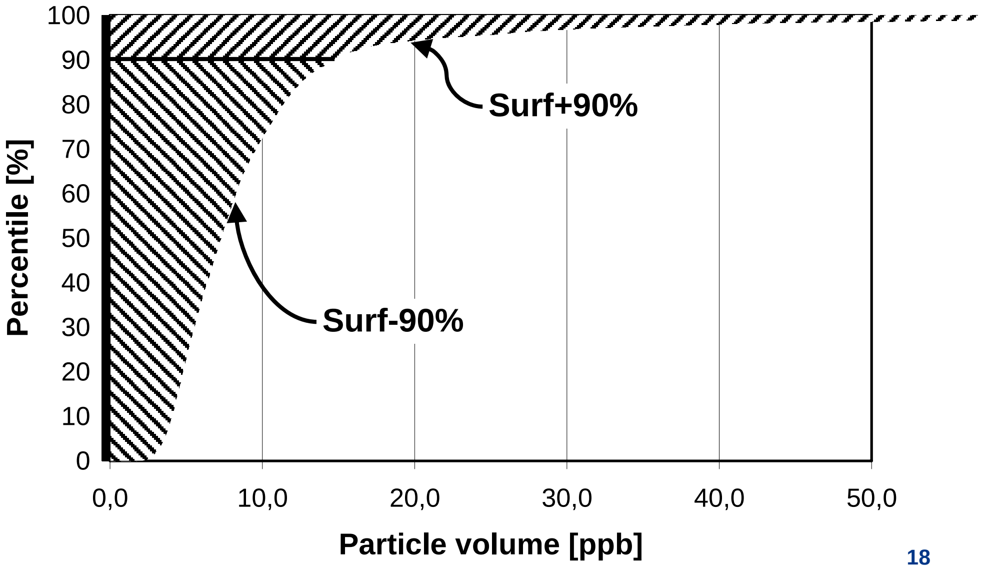
Input particle volume



Particle count/volume data

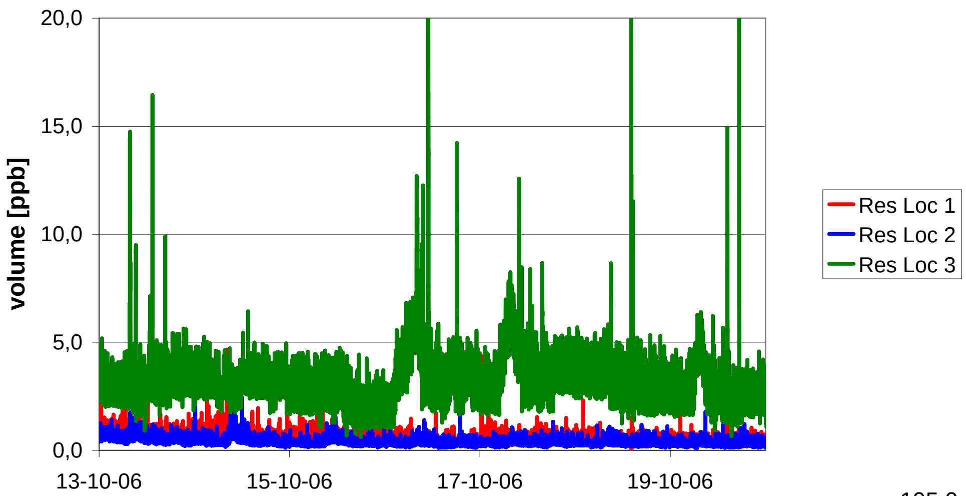


Frequency percentile [%]	[ppb]
90,0	14,57
95,0	21,80
98,0	40,18
99,0	58,39
99,5	84,15
99,9	160,58
ratio 90/99,5	0,17
average [ppb]	9,85
surf -90 [%]	66,4%
surf +90 [%]	33,6%



Research Area second period

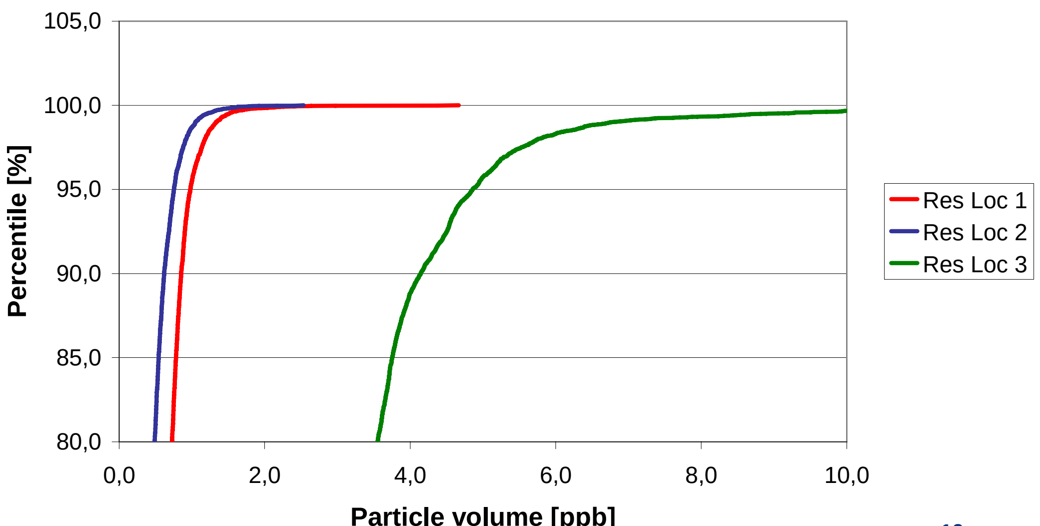
Volume particles Research Area



Frequency percentile [%]	Res Loc 1 [ppb]	Res Loc 2 [ppb]	Res Loc 3 [ppb]
90,0	0,85	0,62	4,15
95,0	0,98	0,75	4,86
98,0	1,18	0,92	5,76
99,0	1,33	1,05	6,78
99,5	1,51	1,21	8,90
99,9	2,17	1,62	16,39

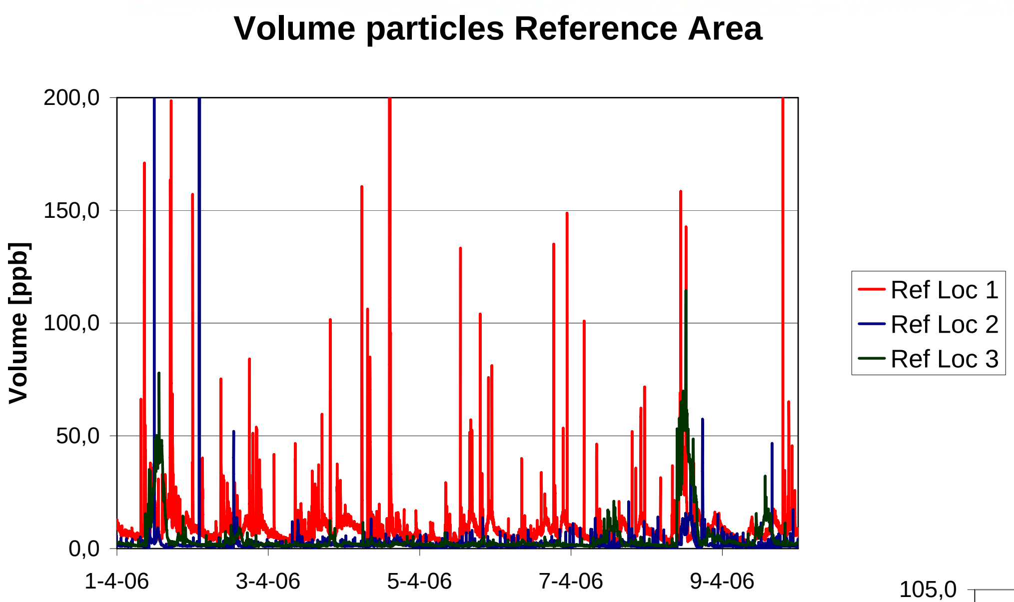
ratio 90/99,5	0,56	0,51	0,47
average [ppb]	0,55	0,38	2,93
surf -90 [%]	80,7%	78,7%	80,9%
surf +90 [%]	19,3%	21,3%	19,1%

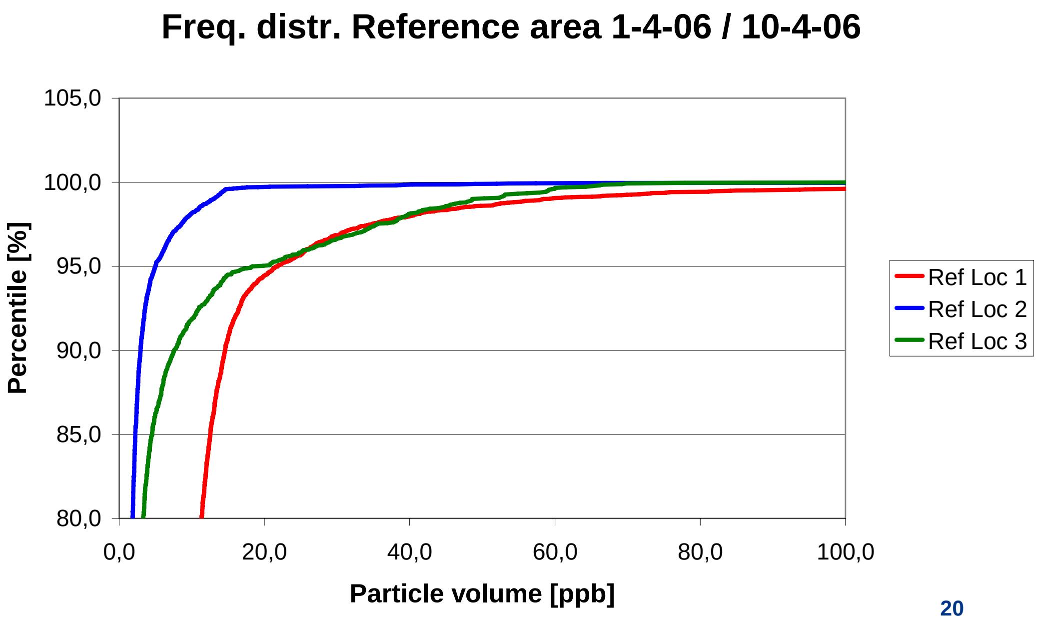
Freq. Distr. Research Area 13-10-06 / 20-10-06



Reference Area first period

Frequency percentile [%]	Ref Loc 1 [ppb]	Ref Loc 2 [ppb]	Ref Loc 3 [ppb]
90,0	14,57	2,95	7,55
95,0	21,80	5,00	18,32
98,0	40,18	9,56	39,45
99,0	58,39	12,94	48,60
99,5	84,15	14,42	59,09
99,9	160,58	49,01	69,25
ratio 90/99,5	0,17	0,20	0,13
average [ppb]	9,85	1,98	4,49
surf -90 [%]	66,4%	56,6%	43,8%
surf +90 [%]	33,6%	43,4%	54,9%





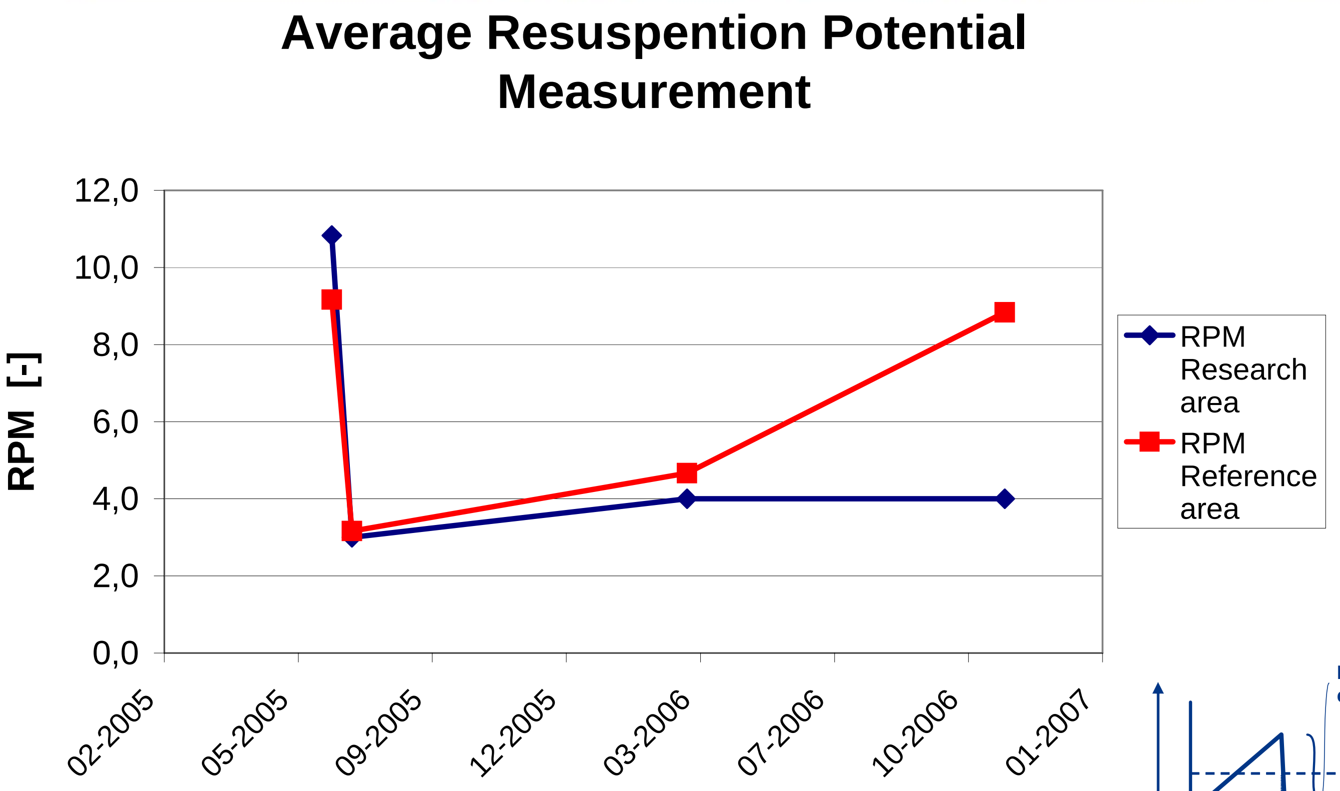
Resuspension Potential Measurements Adjusted (100 m; 0,35 m/s, 5 minutes)

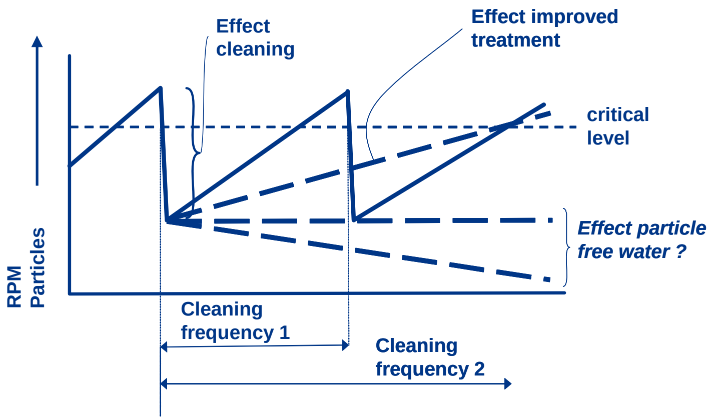
Points	0	1	2	3	4
Max during disturbance [FTU]	<1	1 -3	3 – 5	5 – 10	>10
Average during disturbance [FTU]	<1	1 -3	3 – 5	5 – 10	>10
Resettling time [min]	<1	1-5	5-10	10-15	>15

Research area	-1 measure				0-measure				1-measure				2-measure			
Date	24-6-2005				13-7-2005				14-3-2006				6-11-2006			
location				tot				tot				tot				tot
Res loc 1	4	4	3	11	1	1	1	3	2	1	0	3	3	3	2	8
Res loc 2	4	4	4	12	1	1	1	3	4	3	0	7	2	1	0	3
Res loc 3	4	4	3	11	1	0	1	2				0	2	1	0	3
Res loc 4	4	4	2	10	0	0	0	0	1	1	0	2	1	1	0	2
Res loc 5	4	4	3	11	2	1	2	5				0	1	1	0	2
Res loc 6	4	4	2	10	3	1	1	5				0	4	2	0	6
Average				10,83				3,00				4,00				4,00

Reference area	-1 measure				0-measure				1-measure				2-measure			
Date	22-6-2005				7-7-2005				14-3-2006				6-11-2006			
location				tot				tot				tot				tot
Ref loc 1	3	2	2	7	1	1	1	3	0	0	0	0	0	0	0	0
Ref loc 2	4	4	3	11	2	1	1	4	4	4	2	10	4	4	3	11
Ref loc 3	4	4	4	12	2	1	1	4				0	4	4	2	10
Ref loc 4	3	3	1	7	4	3	1	8	3	1	0	4	4	4	3	11
Ref loc 5	4	3	3	10	0	0	0	0				0	4	4	2	10
Ref loc 6	4	3	1	8	0	0	0	0				0	4	4	3	11
Average				9,17				3,17				4,67				8,83

RPM graphical

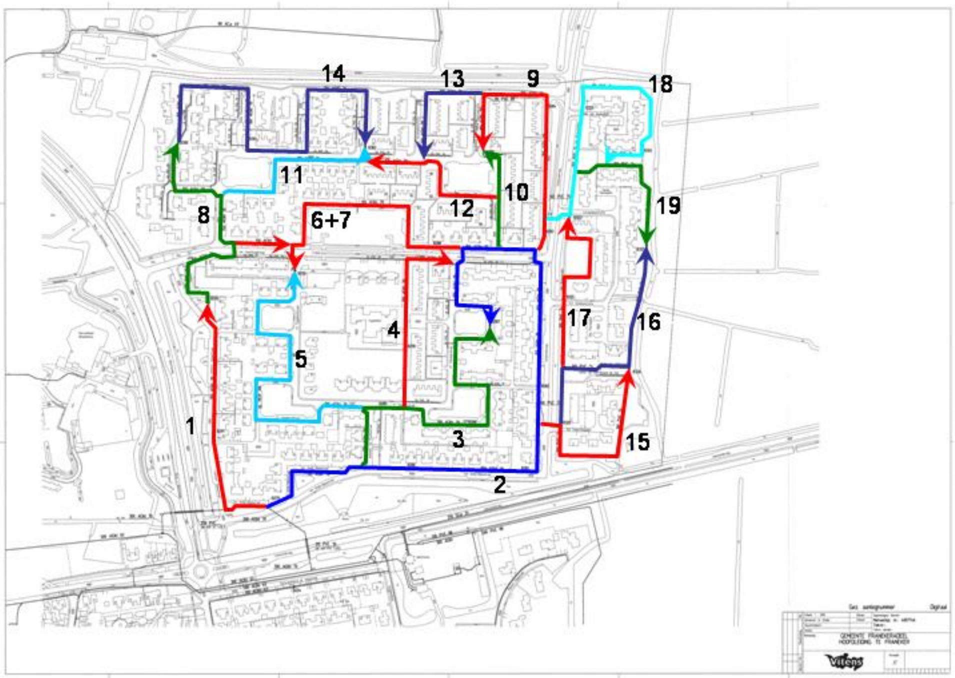


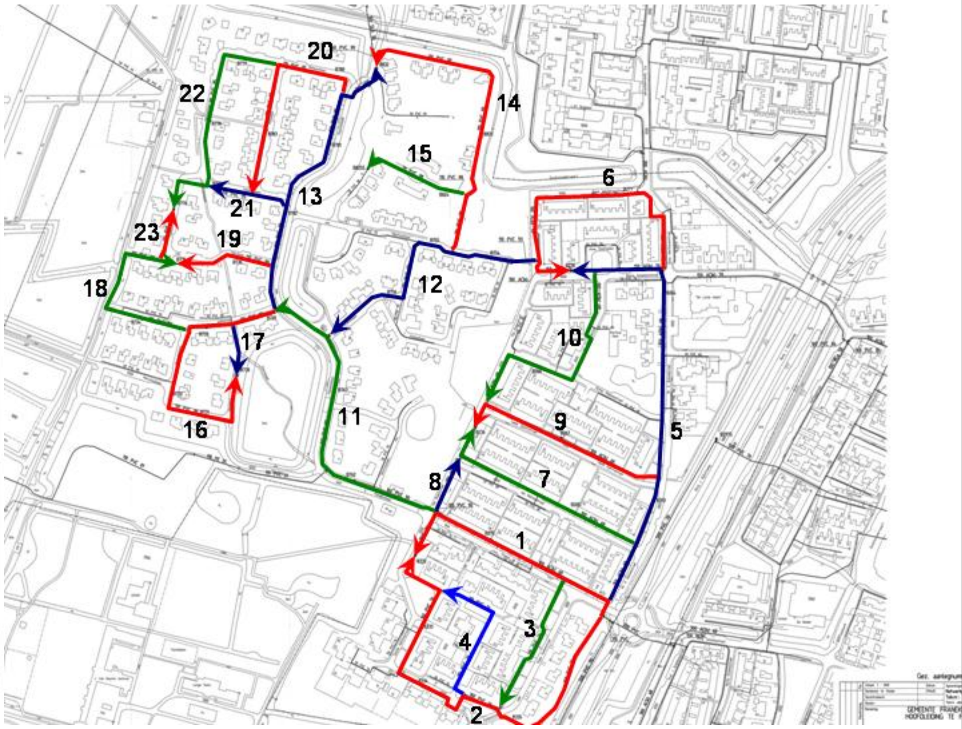


How much sediment is accumulated: Clean both the areas

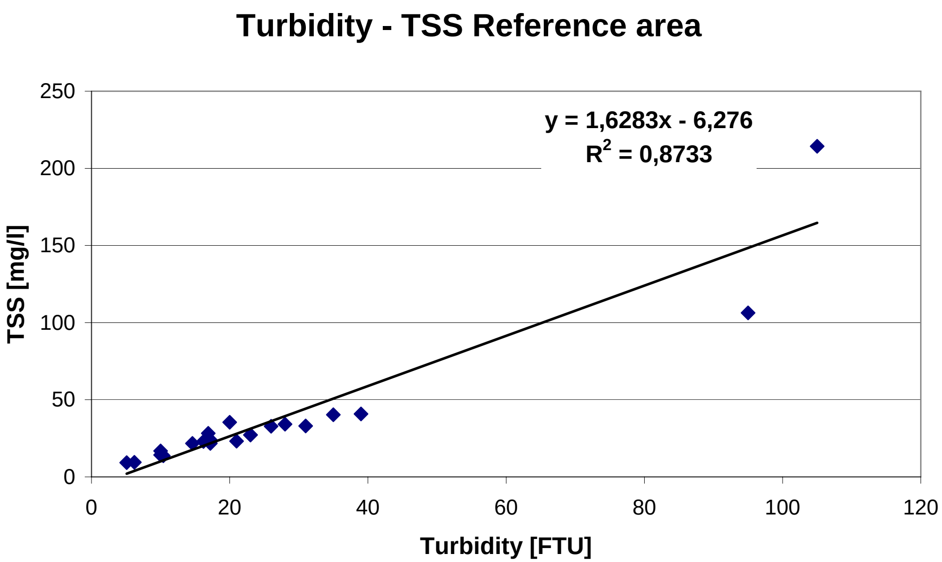
- Dedicated flushing program (1,5 m/s, uni-directional flow, clear water front)
- Continuous monitoring turbidity of flushed water
- Samples in first turn over flushed water
- Analysis samples for calibration curve TSS-FTU

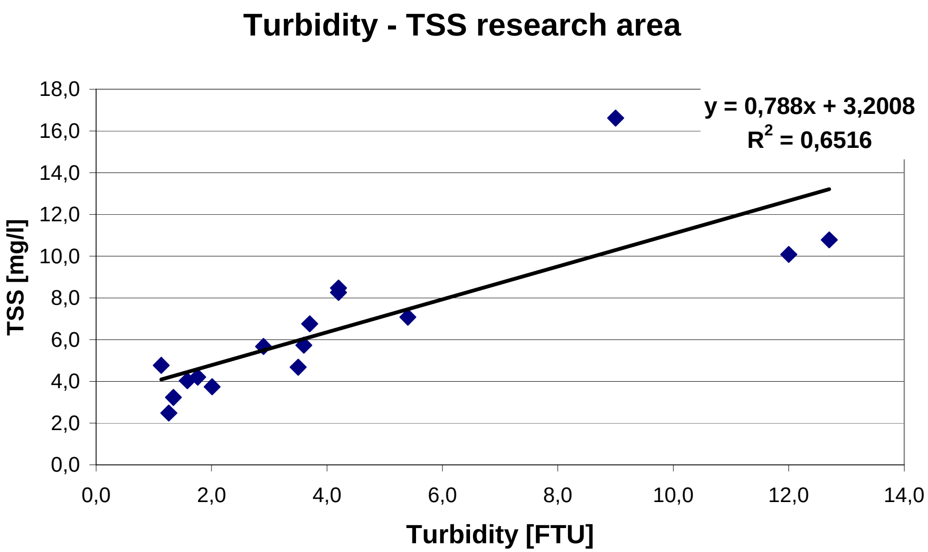
Flush plans Research Area and Reference Area





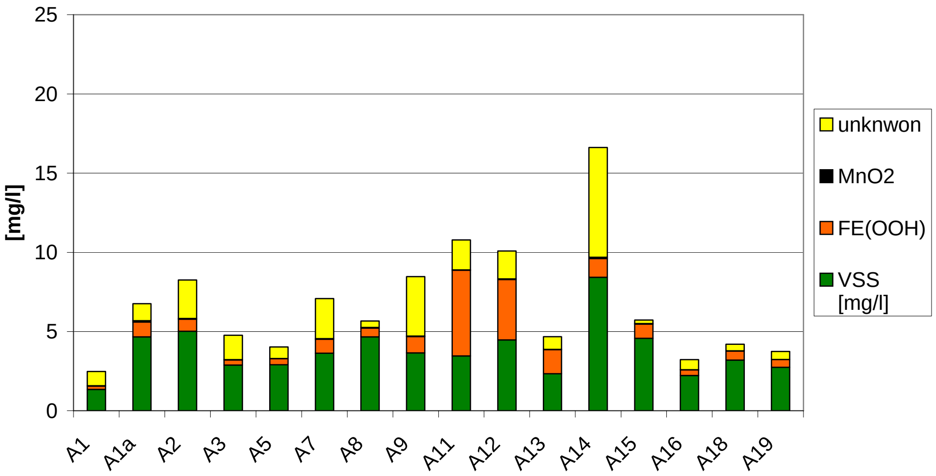
Relation TSS-Turb



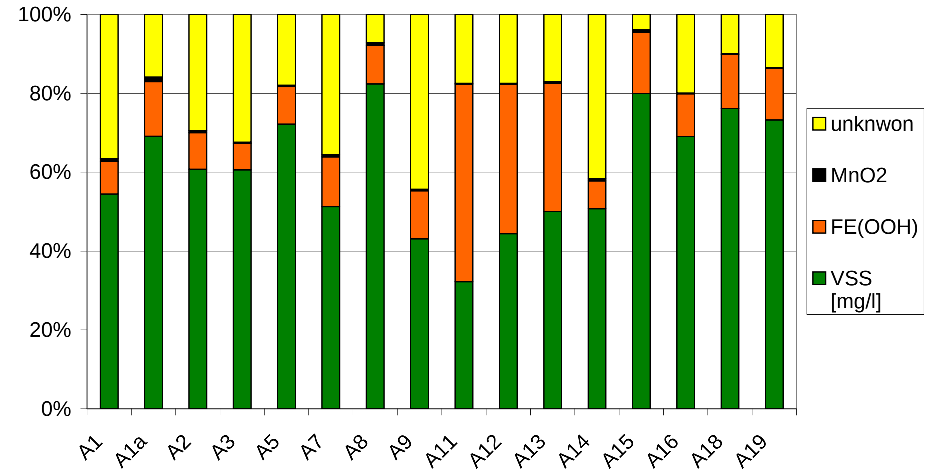


Sample analyses

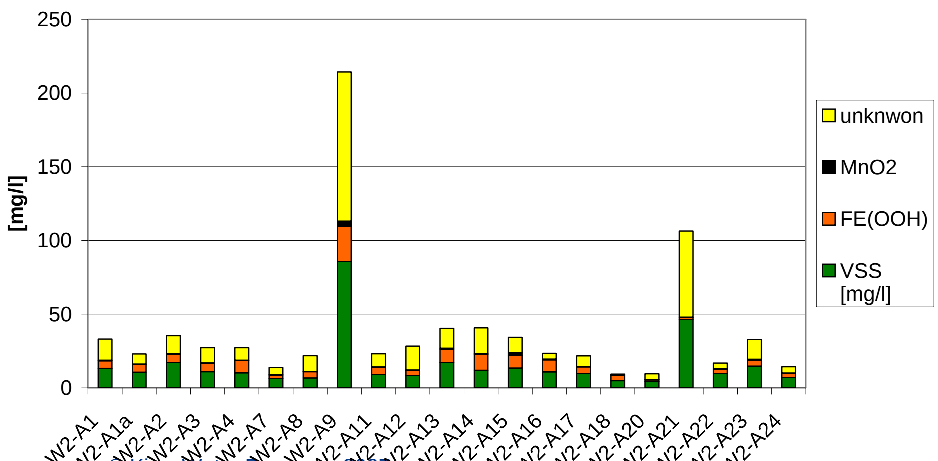
Composition flush samples Research Area



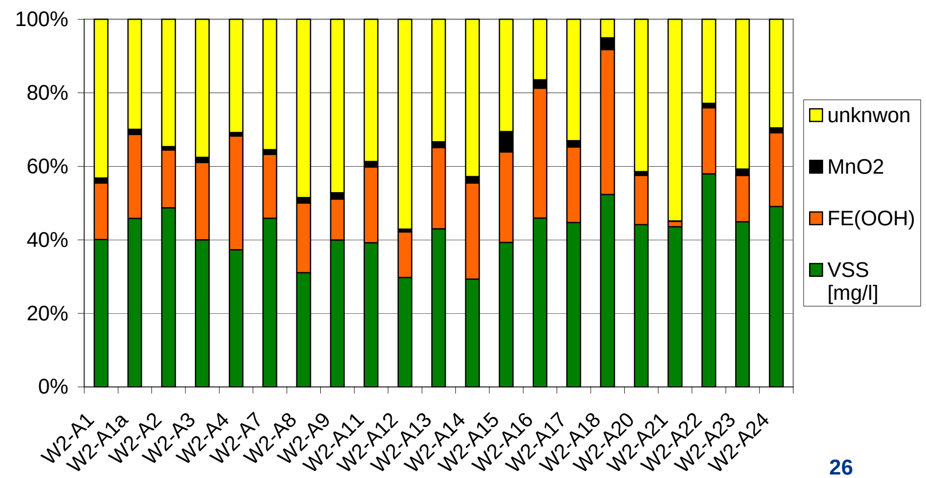
Relative comp. flush samples Research Area



Composition flush samples Reference Area



Relative comp. flush samples Reference Area



Removed TSS during flushing

	Total length flushed [m]	Removed TSS [gr]	Removed TSS per meter [mg/m]
Research	5840	525,08	89,9
Reference	5370	5752,52	1071,2

Conclusion: sediment originates mostly from the treatment

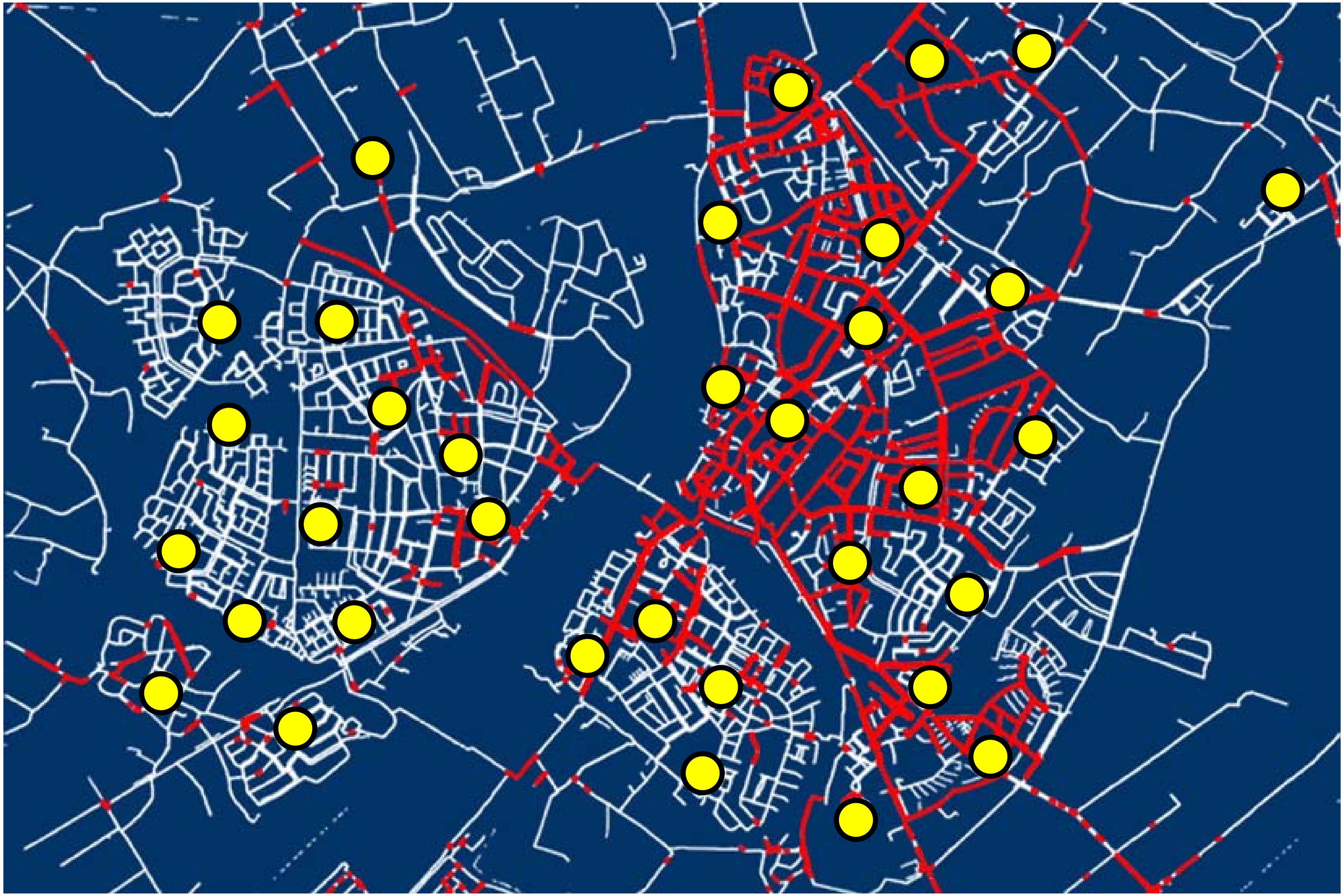
What can we do in the network

- **Clean the network: Flush with water**
  - **1,5 m/s**
  - **Clear water front**
  - **2 to 3 times turn over**
- **Design on self cleaning networks**

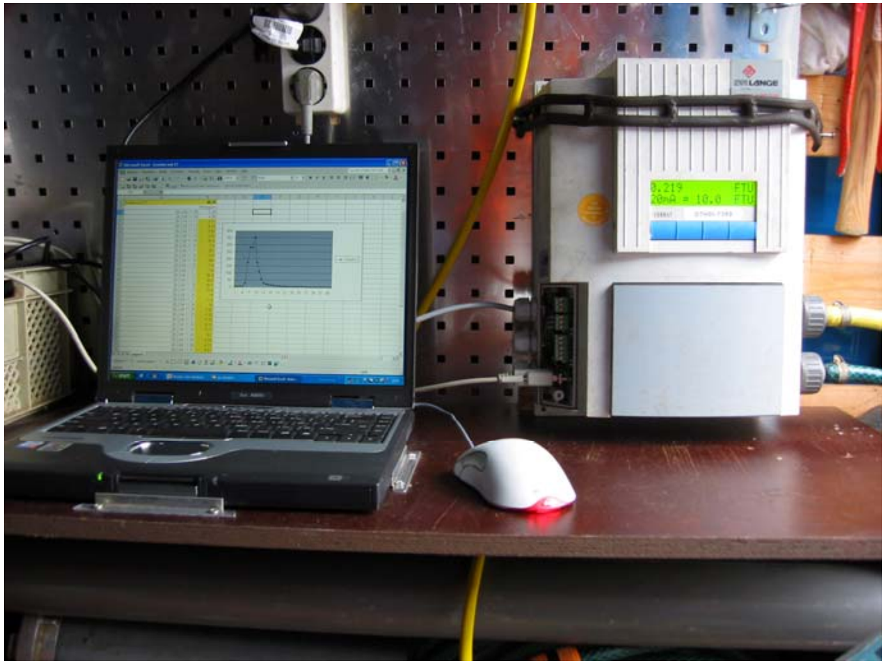
Clean the network: uni-directional flushing: a case study

- The network of Venlo
  - Partly Cast iron
  - Partly Asbestos Cement
- Cleaning in 2002
- Treatment improved during 2004
- Monitoring with adjusted RPM

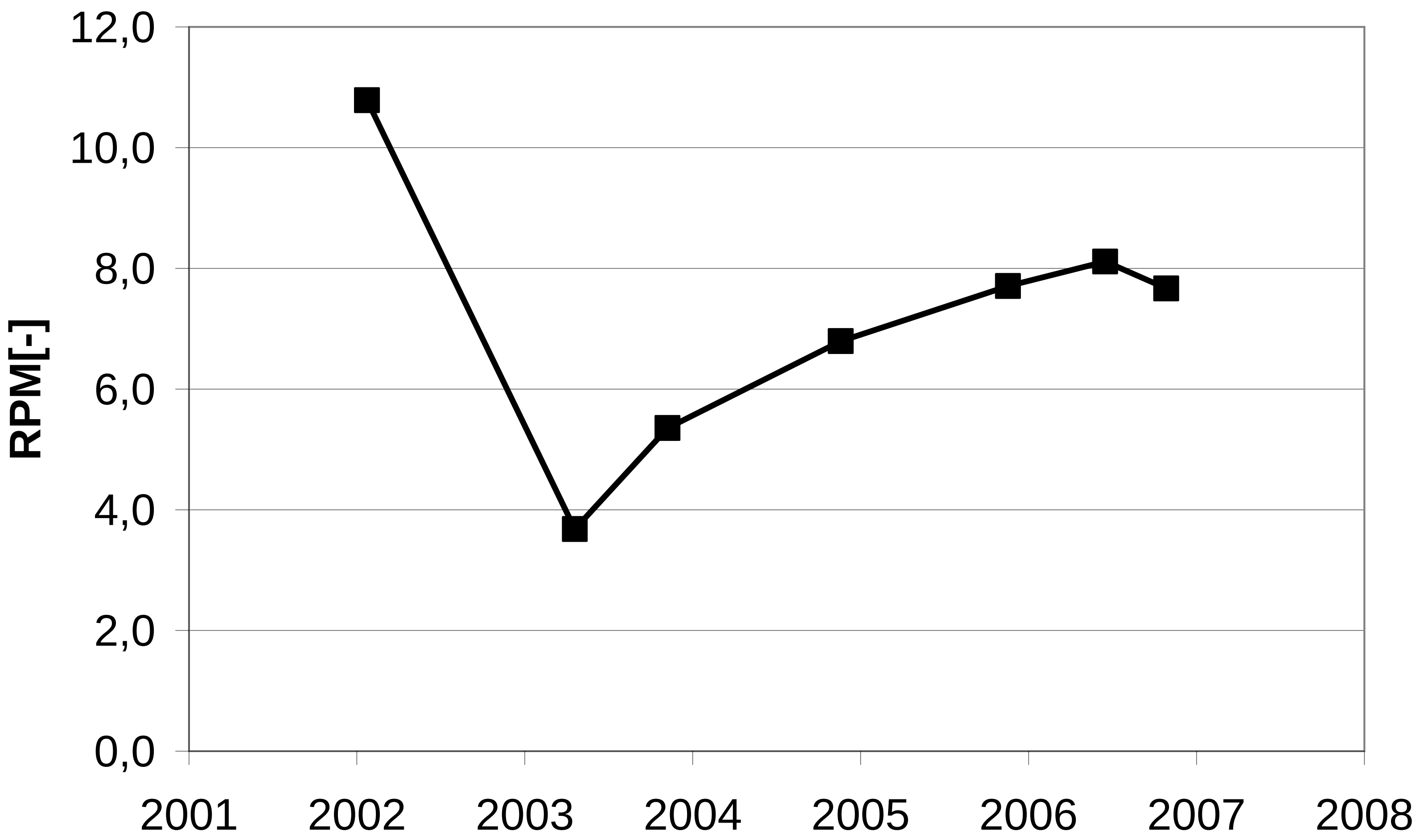
The network and monitor locations



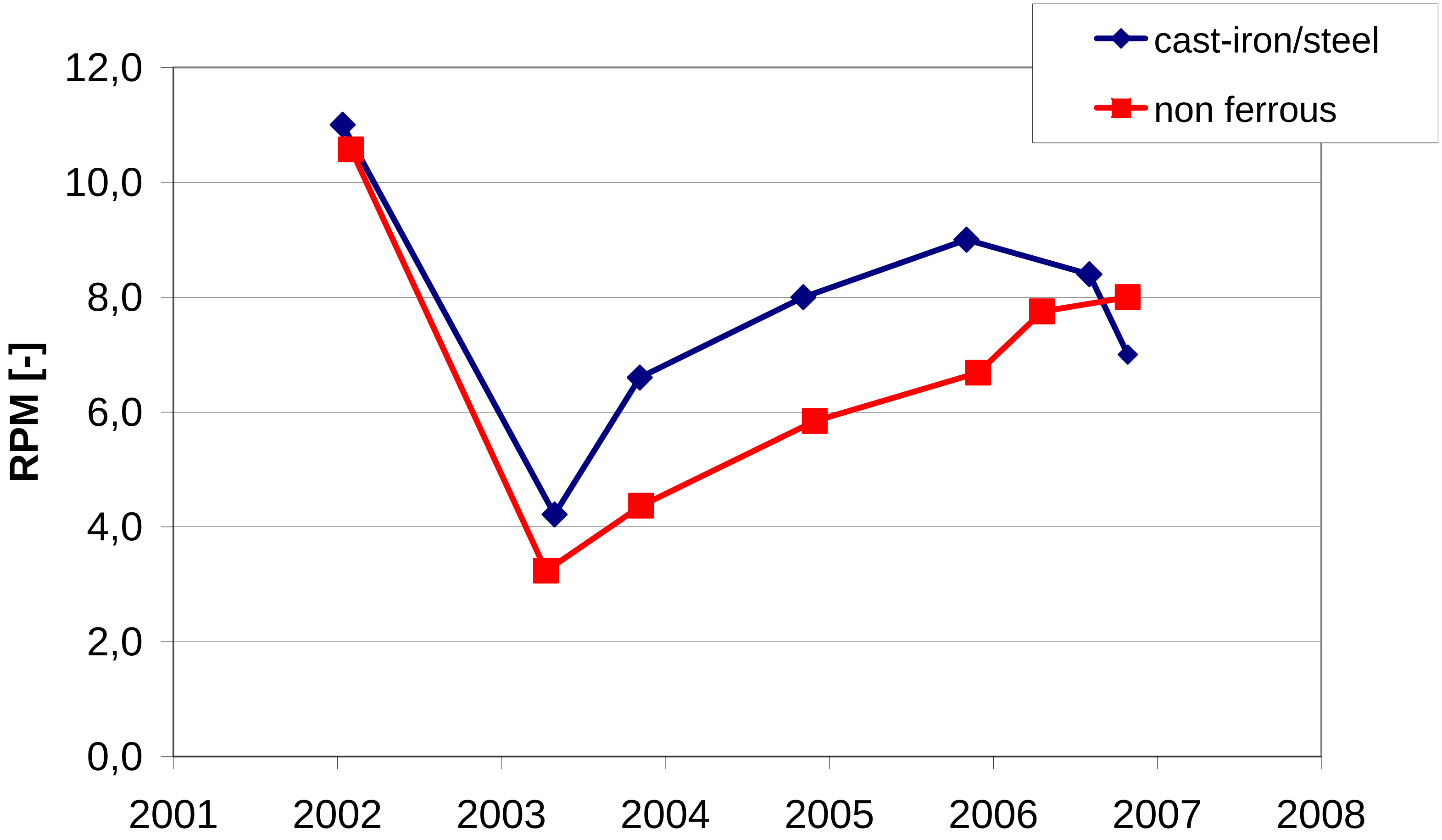
The monitoring equipment



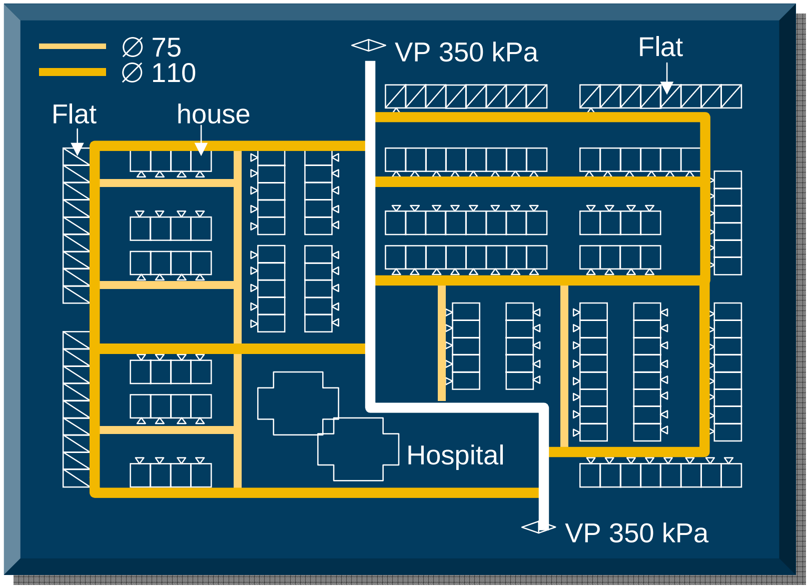
The results
Average Adjusted RPM

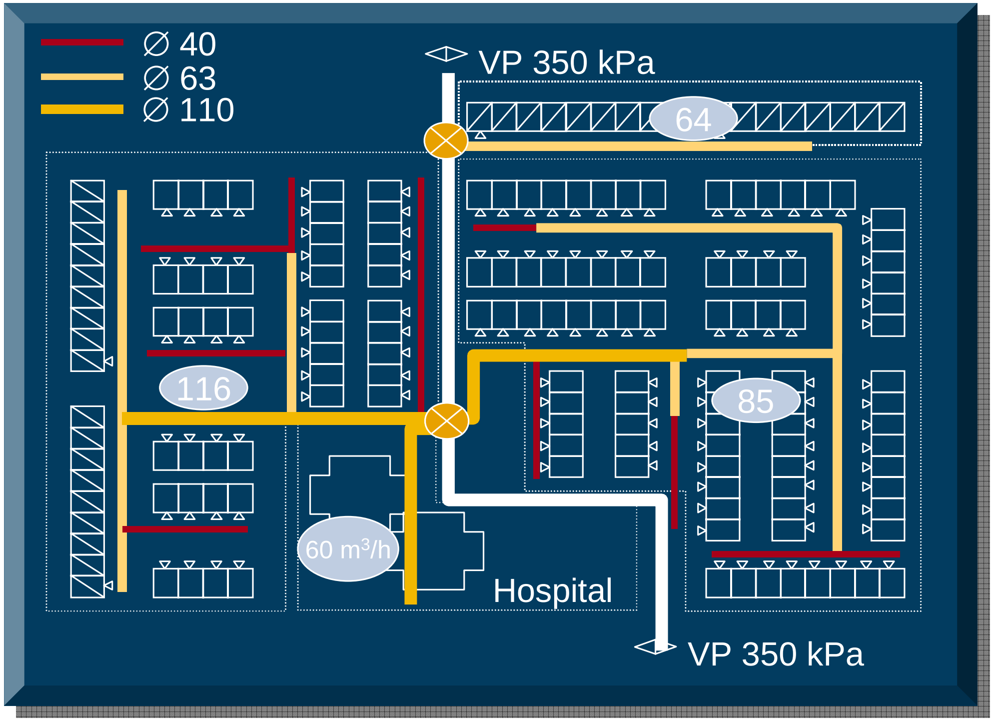


Average Adjusted RPM sorted by material

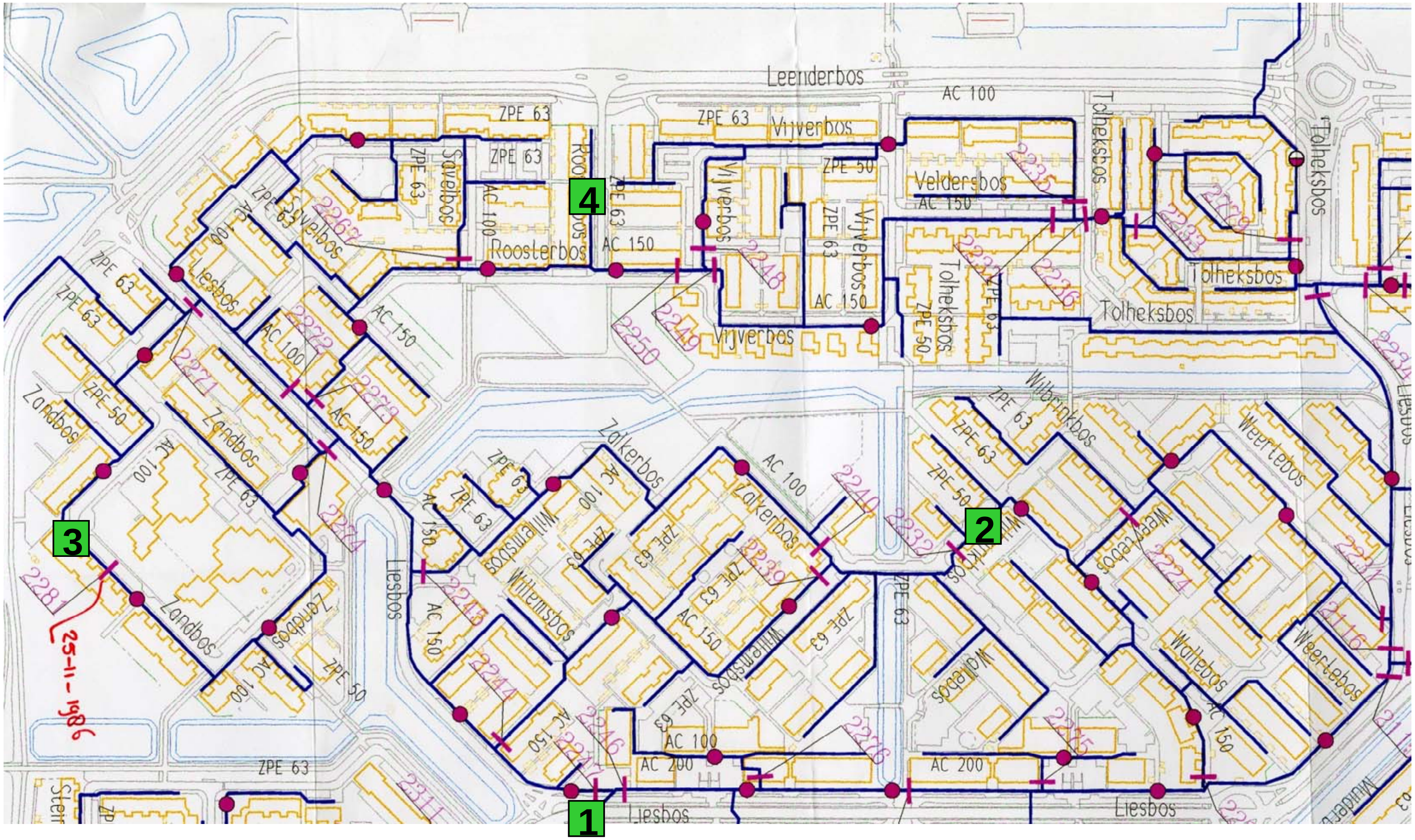


Self cleaning networks: the principle



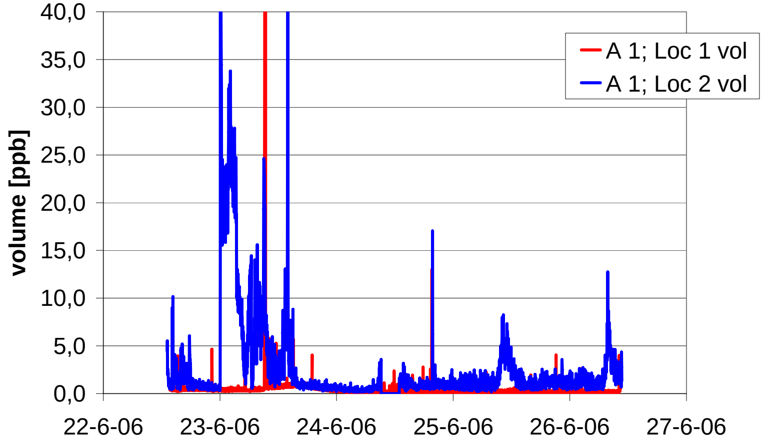


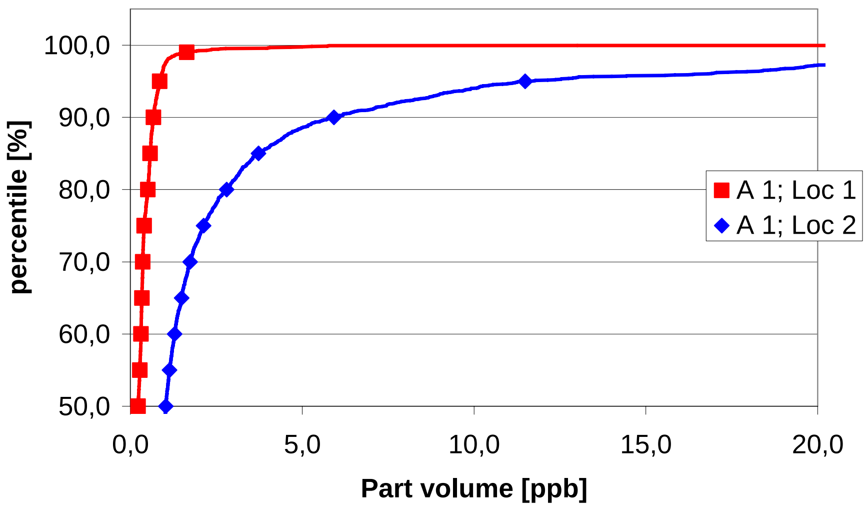
Self cleaning networks: case study comparing to conventional network

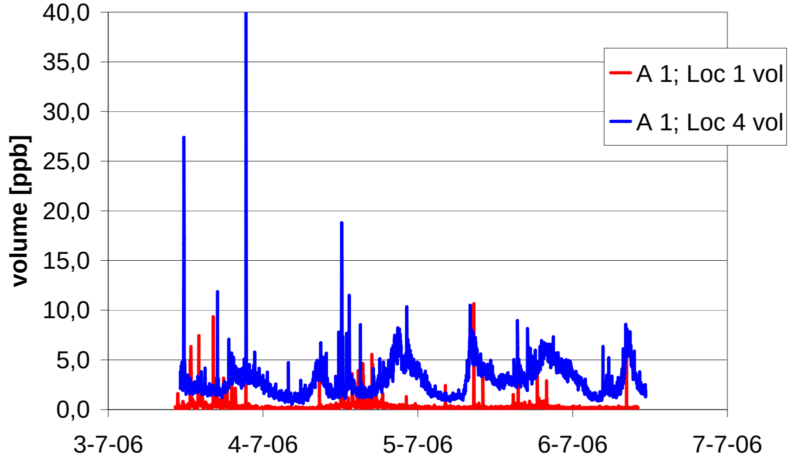


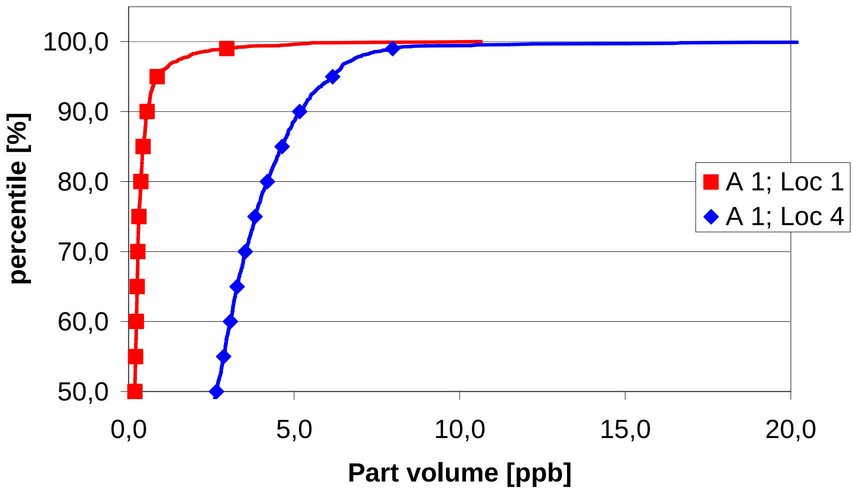
Self cleaning network

Area 1: conventional

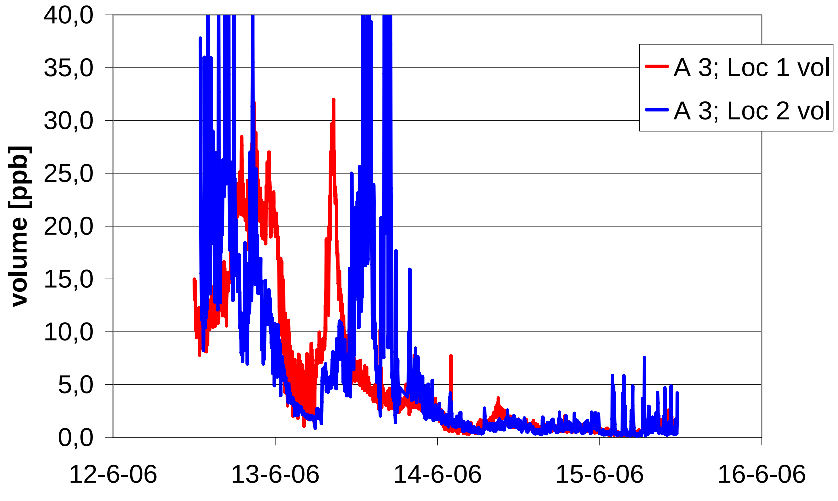


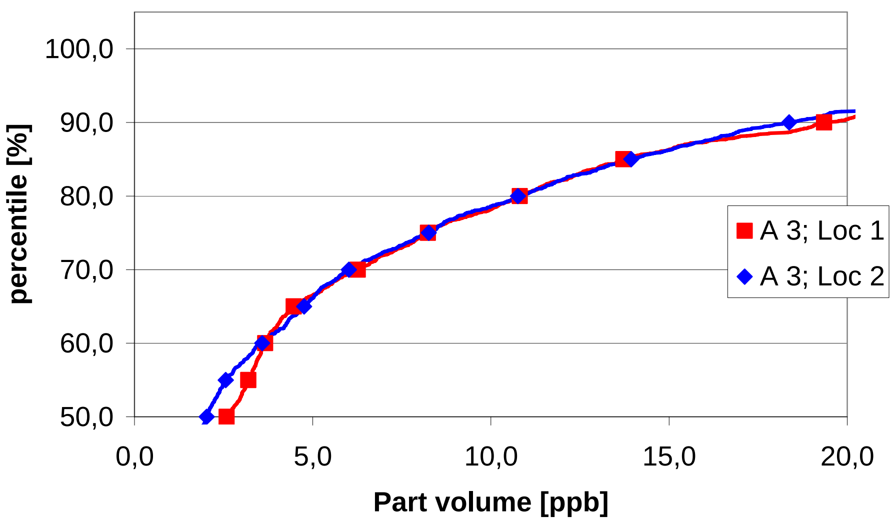


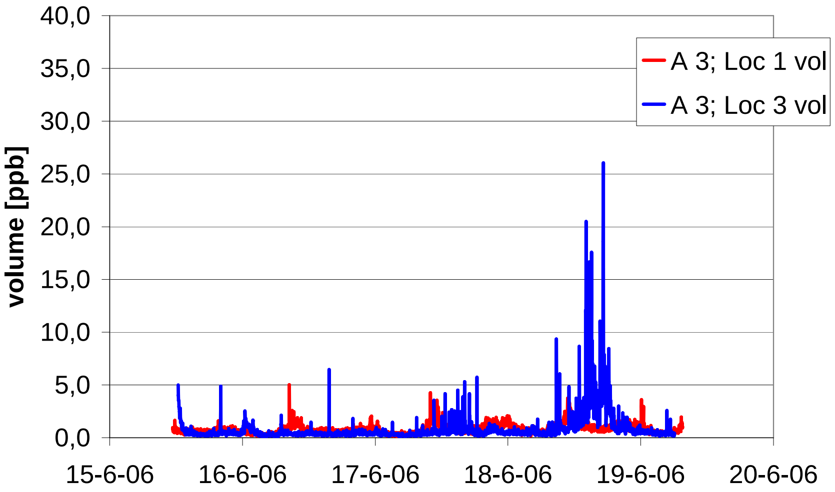


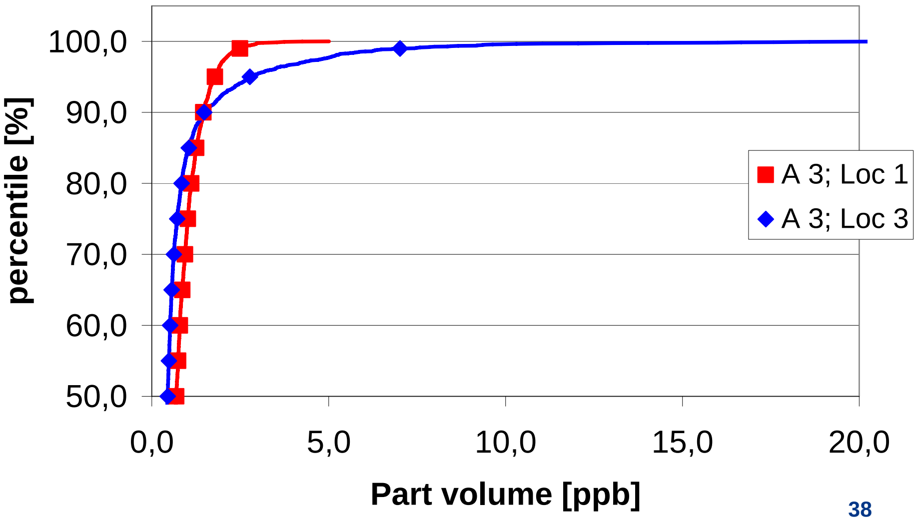


Area 3: self cleaning

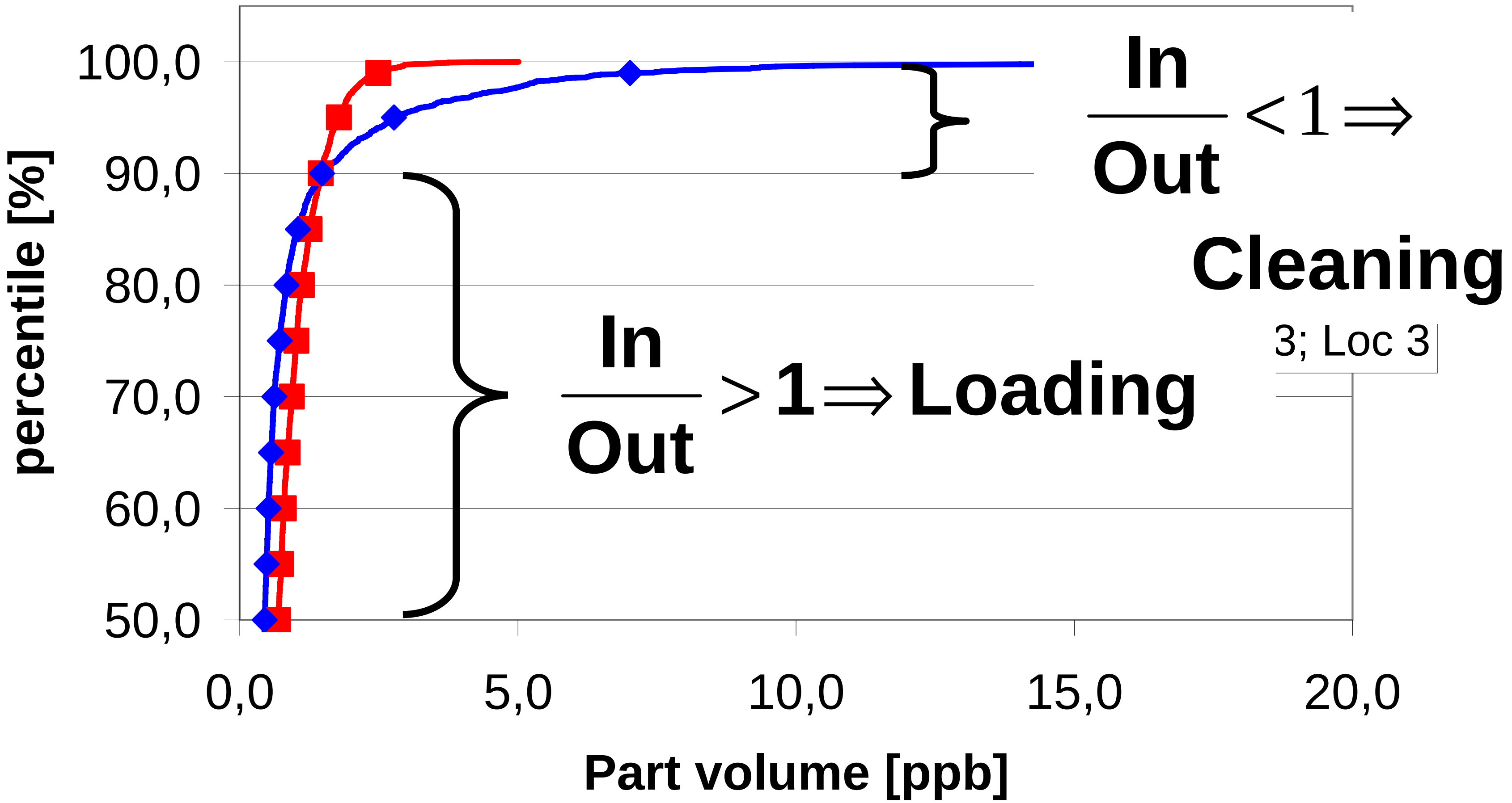




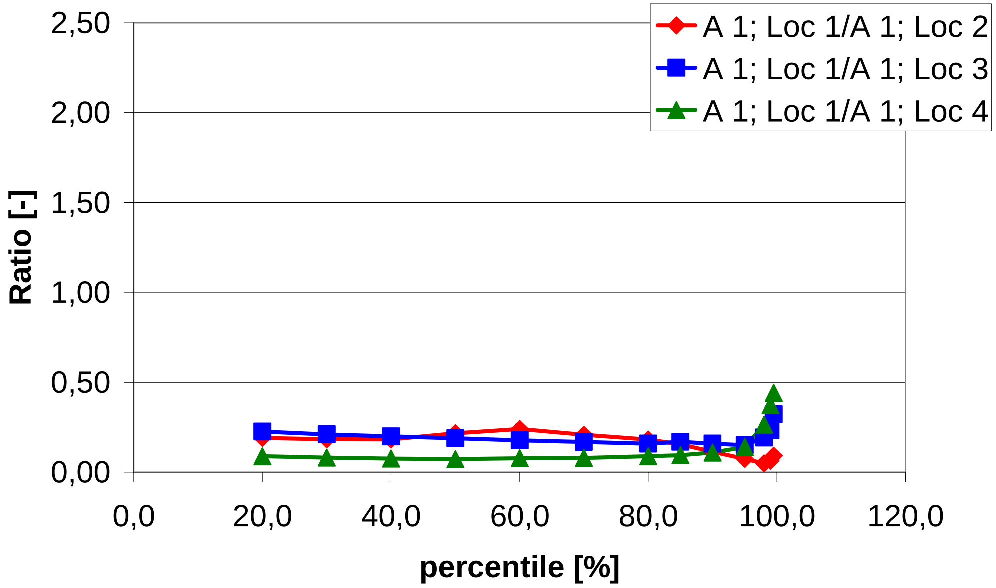


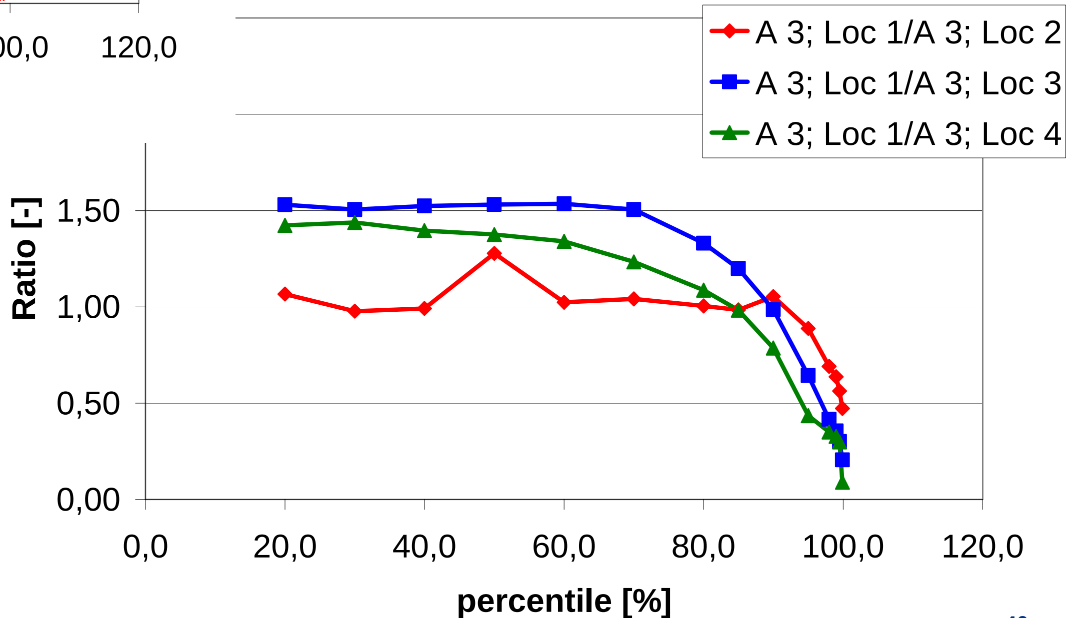


Ratio in going / out going



Comparison conventional ←→ Self cleaning Ratio In/Uit in different locations





Conclusions

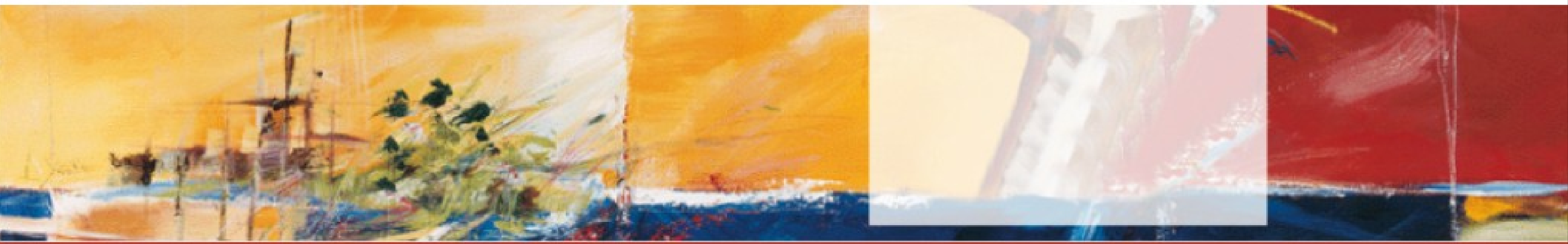
- Sediment primairily originates from treatment
- Particle load in Reference Area reloads the system in one-and-a-half year to starting level
- Particle free water decreases cleaning frequency with factor 5-10
- Avoiding peaks will decrease the particle load significantly
- Dedicated flushing works
- Self cleaning network are self cleaning

Jan Vreeburg

UNESCO-IHE Institute for Water Education

TU Delft Technische Universiteit Delft

kiwa Partner for progress



Particles in the distribution system

Delft Cluster

TECHNEAU

21-06-2007

Q21