# Grondwaterzuivering

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Technische Universiteit Delft

# Kenmerken grondwater

Voordelen

- hygiënische betrouwbaarheid
- constante temperatuur
- biologische en chemische stabiliteit
- gelijkmatige goede kwaliteit
- ongevoelig voor calamiteiten

Nadelen

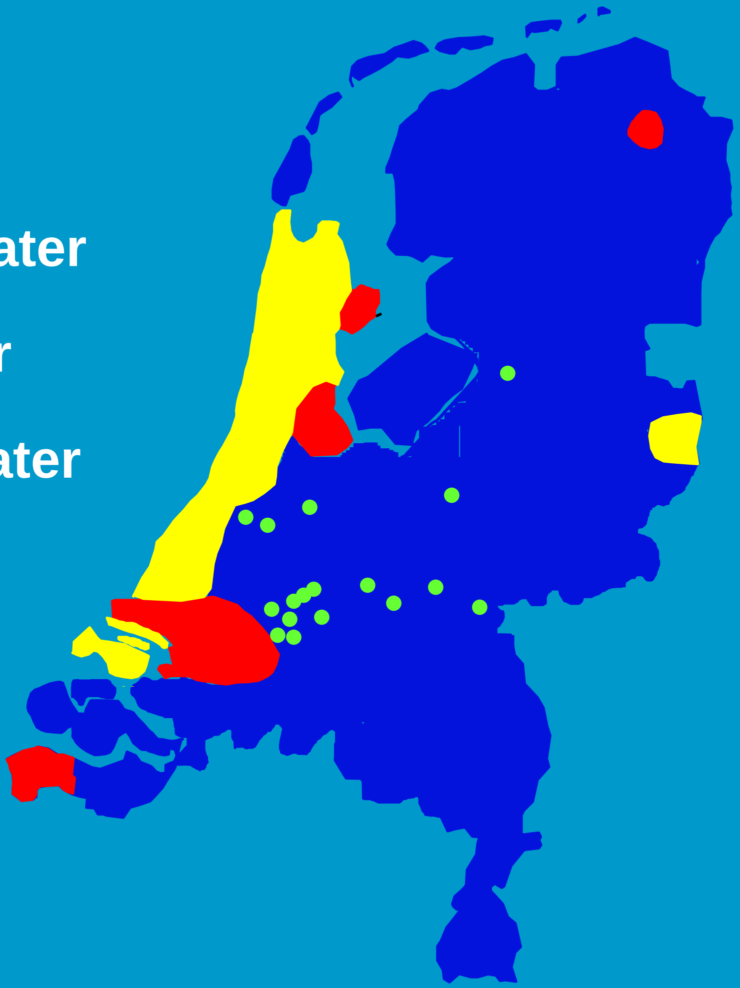
- beperkte beschikbaarheid
- vrij groot ruimtebeslag

Opzet infrastructuur

- kleinschalig

# Bronnen van drinkwater

- grondwater
- oppervlaktewater
- infiltratiewater
- oevergrondwater



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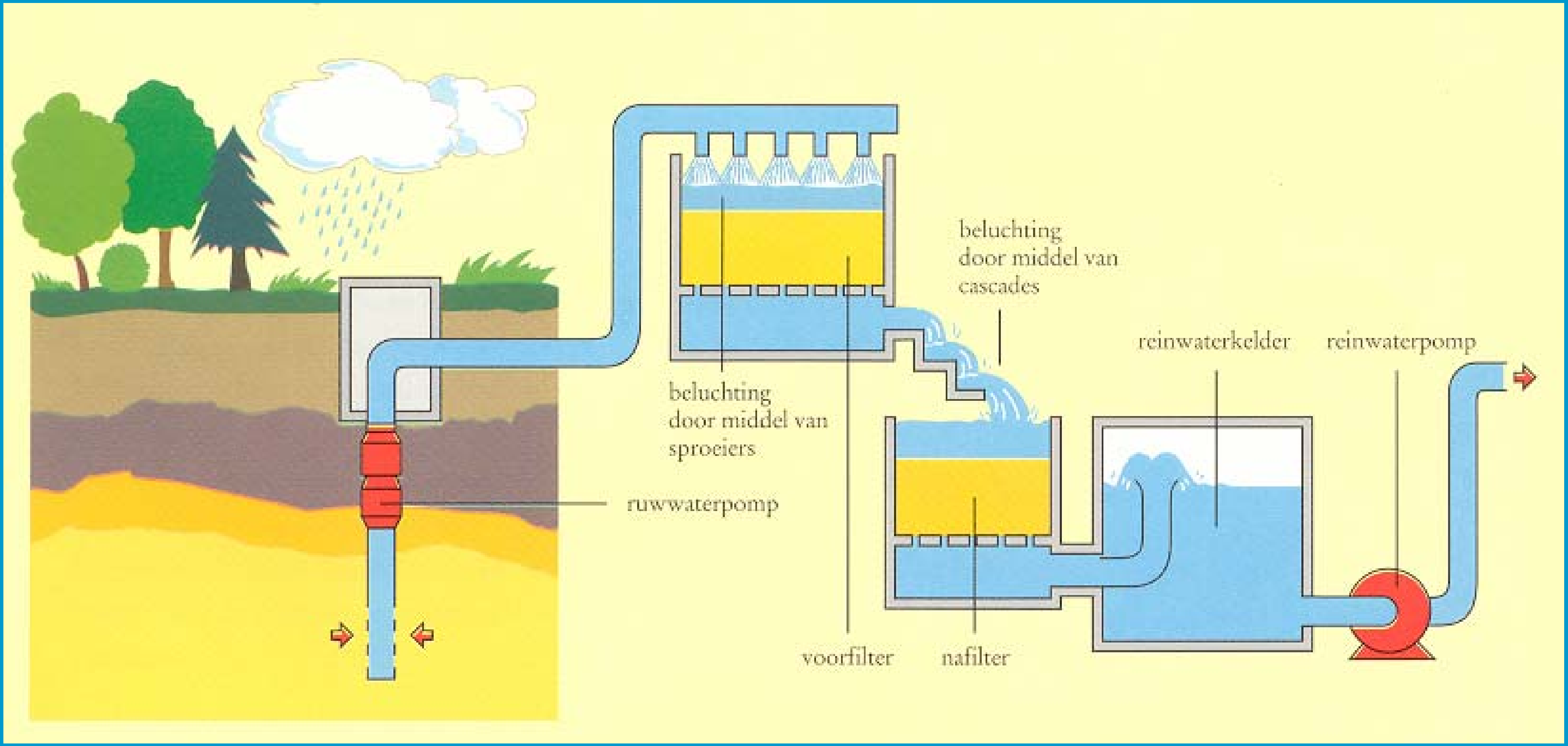
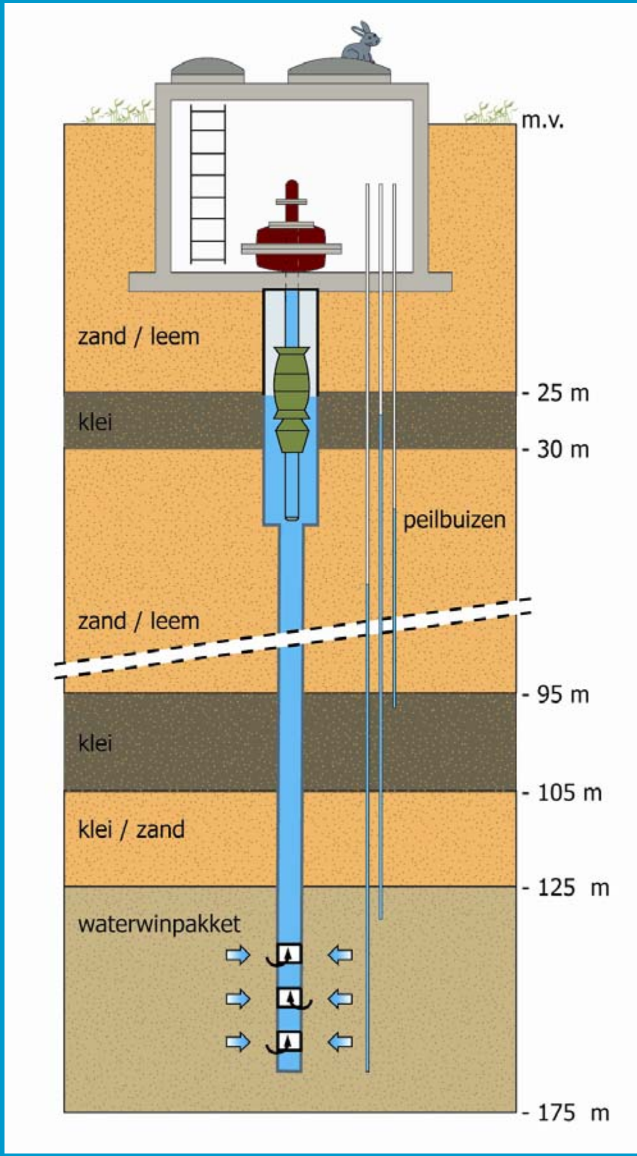
# Grondwaterzuivering



# Winputten

# Winning

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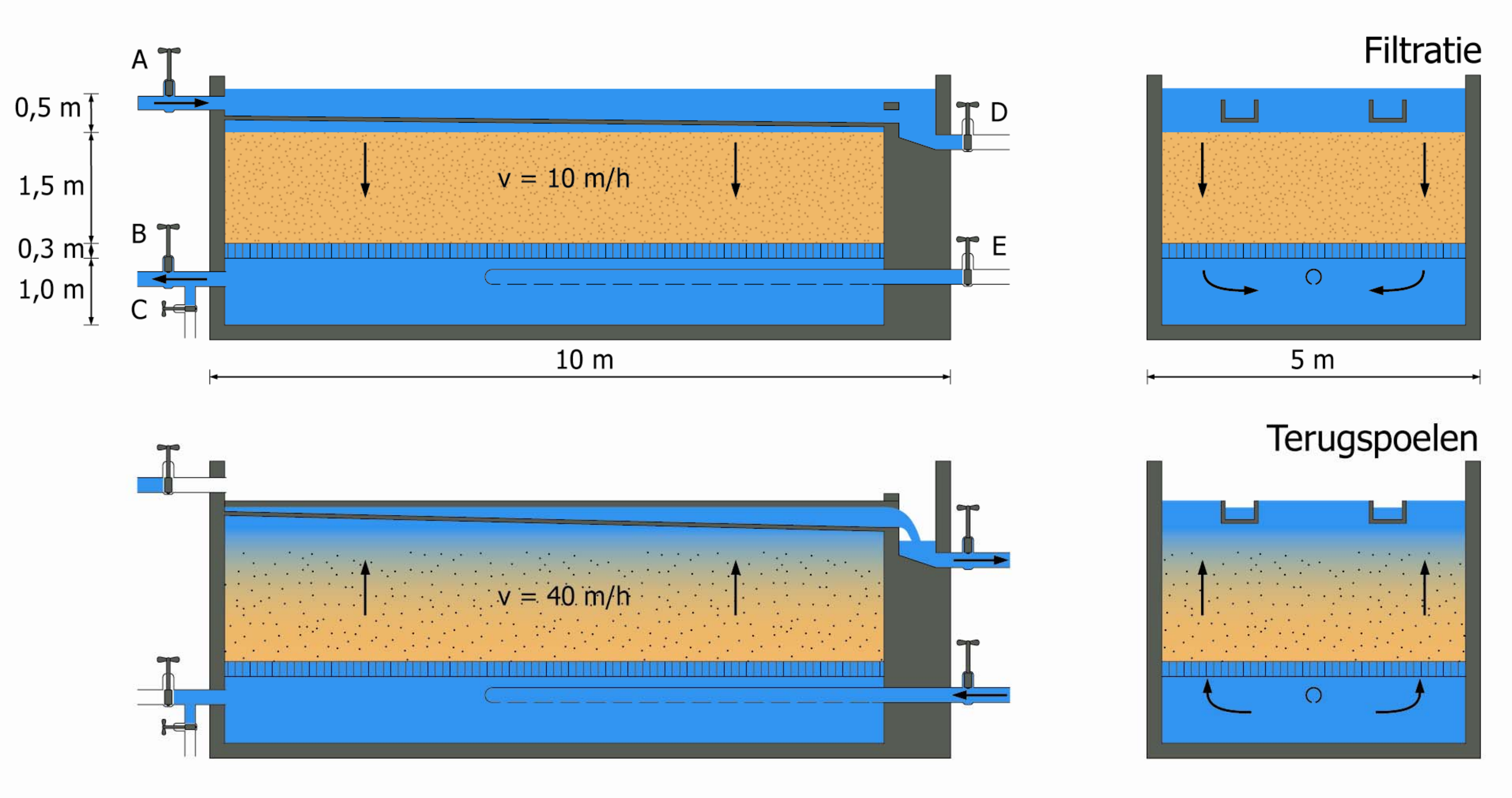
# Beluchting

# Beluchting

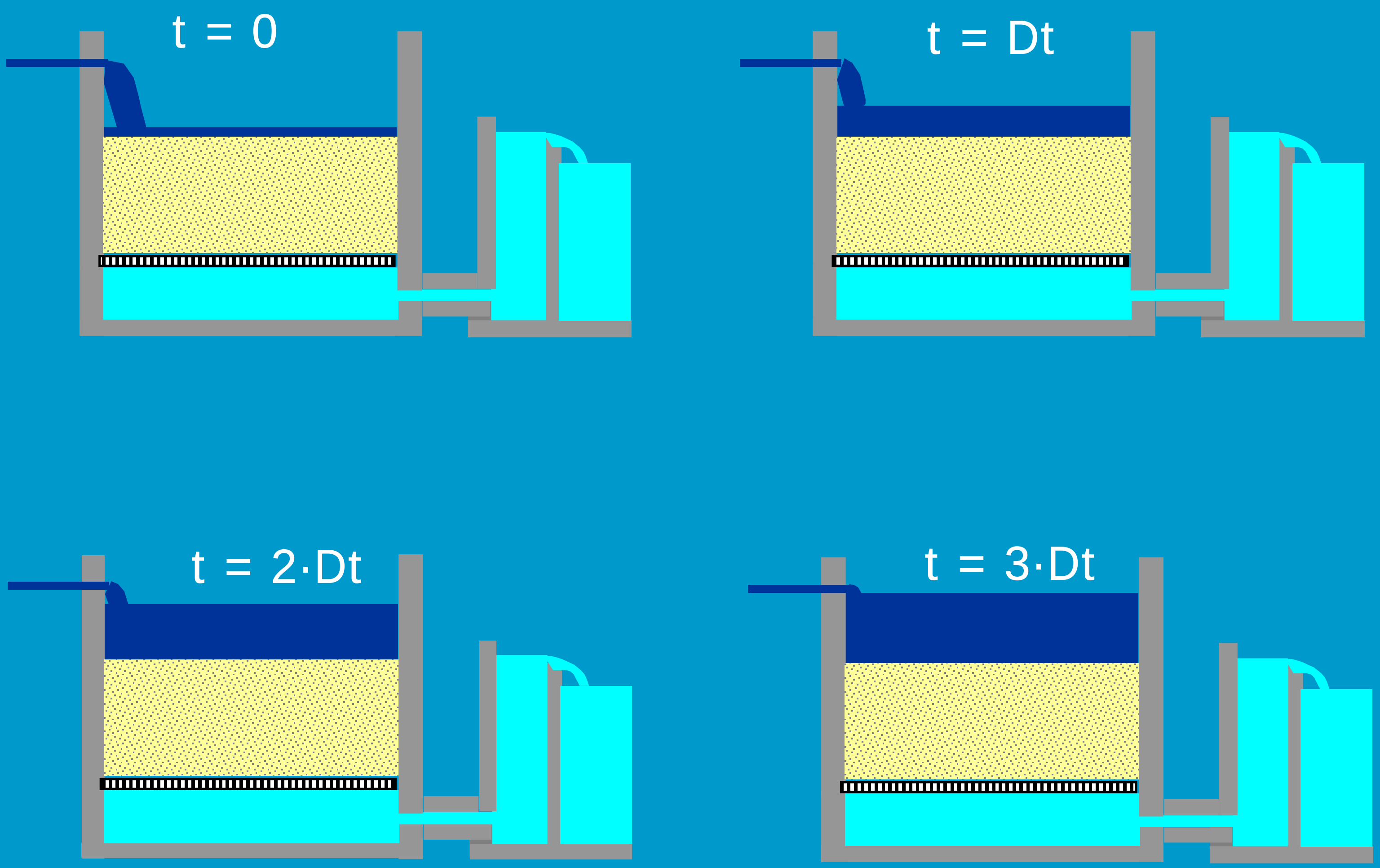
Cascade

Sproeibeluchting

# Grondwaterfiltratie

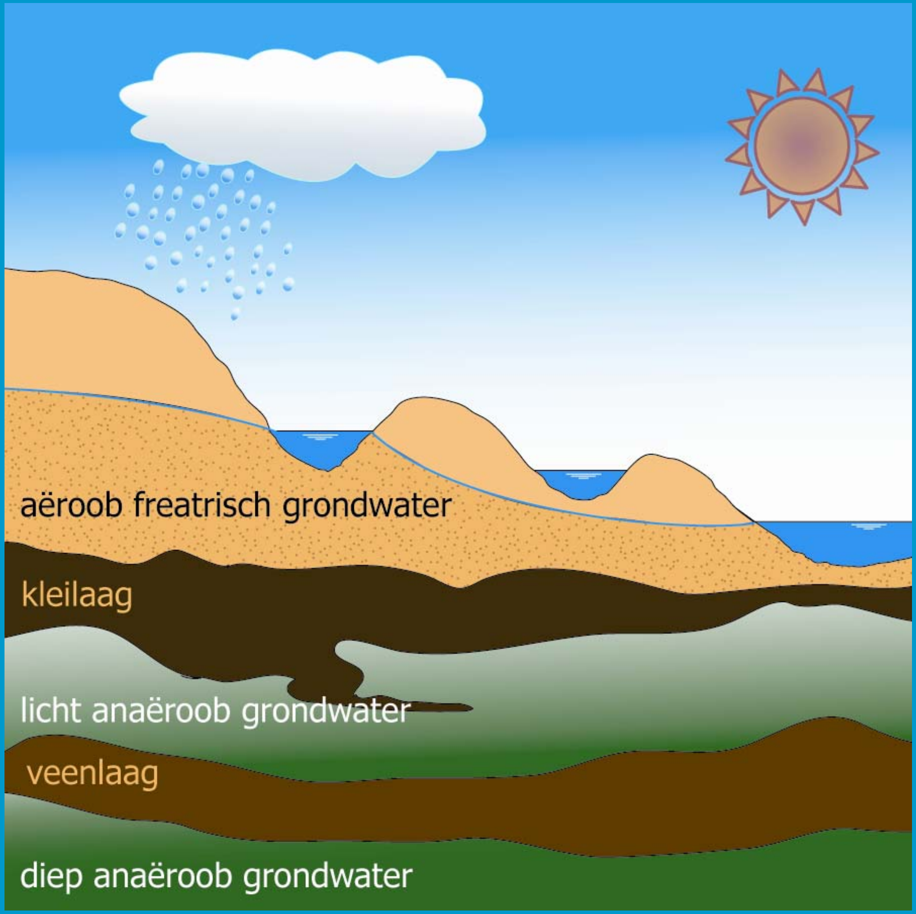


# Toename filterweerstand



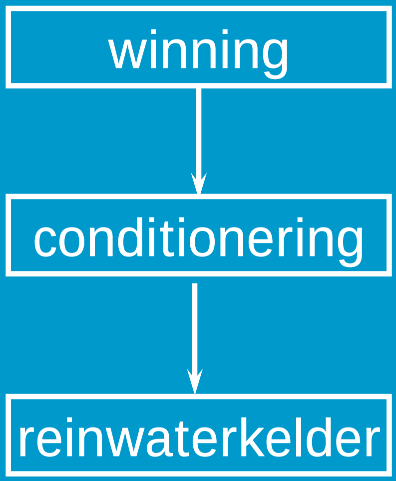
# Terugspoelen

# Soorten grondwater



# Aëroob freatisch grondwater

zuiveringsschema




kenmerken aëroob grondwater:
weinig tot geen zuivering

bij zandgronden:
agressief, lage pH --> marmerfiltratie
$CaCO_3 + CO_2 + H_20 \rightarrow 2\ HCO_3^- + Ca^{2+}$

bij kalkhoudende gronden (Z-Limburg):
kalkafzettend --> ontharding
$NaOH + Ca^{2+} + HCO_3^- \rightarrow CaCO_3 + Na^+ + H_2O$
$Ca(OH)_2 + Ca^{2+} + 2\ HCO_3- \rightarrow 2\ CaCO_3 + 2\ H_2O$



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# Marmerfiltratie & ontharding

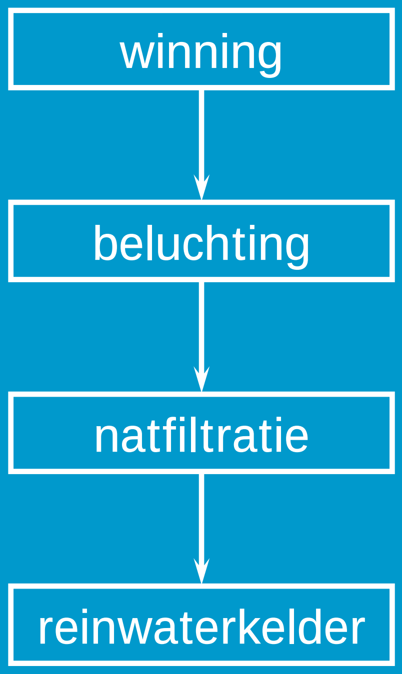
# Aëroob freatisch grondwater

| Parameter | Eenheid | Ruwwater | Reinwater |
|---|---|---|---|
| Temperatuur | °C | 9,6 | 10 |
| pH | - | 6,1 | 7,8 |
| EGV | mS/m | 9,3 | 14,3 |
| SI | - | -3,4 | -0,3 |
| Troebelheid | FTU | - | <0,1 |
| $Na^{+}$ | mg/l | 8,1 | 7,9 |
| $K^{+}$ | mg/l | 1 | 1 |
| $Ca^{2+}$ | mg/l | 8,6 | 22,5 |
| $Mg^{2+}$ | mg/l | 1,6 | 1,6 |
| $Cl^{-}$ | mg/l | 12 | 12 |
| $HCO_3^{-}$ | mg/l | 21 | 63 |
| $SO_4^{2-}$ | mg/l | 9 | 10 |
| $NO_3^{-}$ | mg/l | 2,7 | 2,7 |
| $O_2$ | mg/l | 4,2 | 8 |
| $CH_4$ | mg/l | - | - |
| $CO_2$ | mg/l | 31 | 2 |
| $Fe^{2+}$ | mg/l | 0,06 | 0,03 |
| $Mn^{2+}$ | mg/l | 0,02 | <0,01 |
| $NH_4^{+}$ | mg/l | <0,04 | <0,04 |
| DOC | mg/l | <0,2 | <0,2 |
| E-Coli | n/ 1000 ml | 0 | 0 |
| Bentazon | µg/l | - | - |
| Chloroform | µg/l | - | - |
| Bromaat | µg/l | - | - |

Pompstation Hoenderloo

# Licht anaëroob grondwater

zuiveringsschema




kenmerken licht anaëroob grondwater:
onder afsluitende laag

ammonium, ijzer en mangaan

**Beluchting:**
verwijdering $CO_2$; toename $O_2$
$4\ Fe^{2+} + O_2 + 2\ H_2O + 8\ OH^- \text{-->} 4\ Fe^{3+} + 12\ OH^-$

**Filtratie:**
$Fe^{3+} + 3\ OH^- \text{-->} Fe(OH)_3 \downarrow$
$2\ Mn^{2+} + 4\ OH_- + O_2 + H_2O \text{-->} 2\ MnO_2 + 3\ H_2O$
$NH_4^+ + 2\ O_2 + H_2O \text{-->} NO_3^- + 2\ H_3O^+$

| | |
|---|---|
| 1 mg ijzer gebruikt: | 0.14 mg $O_2$ |
| 1 mg mangaan gebruikt: | 0.29 mg $O_2$ |
| 1 mg ammonium gebruikt: | 3.55 mg $O_2$ |

# Licht anaëroob grondwater

| Parameter | Eenheid | Ruwwater | Reinwater |
|---|---|---|---|
| Temperatuur | °C | 13,1 | 13,1 |
| pH | - | 7,7 | 7,9 |
| EGV | mS/m | 58 | 58 |
| SI | - | -0,0 | 0,1 |
| Troebelheid | FTU | - | <0,1 |
| $Na^{+}$ | mg/l | 75 | 75 |
| $K^{+}$ | mg/l | 6,7 | 6,7 |
| $Ca^{2+}$ | mg/l | 47 | 46 |
| $Mg^{2+}$ | mg/l | 7,8 | 8 |
| $Cl^{-}$ | mg/l | 108 | 110 |
| $HCO_3^{-}$ | mg/l | 185 | 177 |
| $SO_4^{2-}$ | mg/l | <1 | <1 |
| $NO_3^{-}$ | mg/l | <0,1 | 2,8 |
| $O_2$ | mg/l | 0,4 | 9,5 |
| $CH_4$ | mg/l | - | - |
| $CO_2$ | mg/l | 7 | 4 |
| $Fe^{2+}$ | mg/l | 0,39 | 0,03 |
| $Mn^{2+}$ | mg/l | 0,03 | <0,01 |
| $NH_4^{+}$ | mg/l | 0,82 | <0,04 |
| DOC | mg/l | 2 | 1,7 |
| E-Coli | n/ 1000 ml | 0 | 0 |
| Bentazon | µg/l | - | - |
| Chloroform | µg/l | - | - |
| Bromaat | µg/l | - | - |

Pompstation Zutphenseweg



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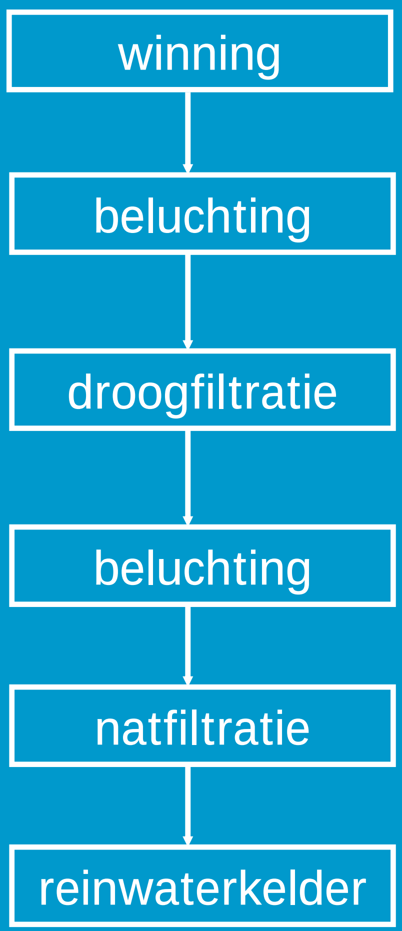
# Diep anaëroob grondwater

zuiveringsschema




kenmerken diep anaëroob grondwater:
onder afsluitende laag

hoge concentratie ammonium,
geen zuurstof en nitraat

Filtratie:

$Fe^{3+} + 3\ OH^- \text{-->} Fe(OH)_3 \downarrow$

$2\ Mn^{2+} + 4\ OH_- + O_2 + H_2O \text{-->} 2\ MnO_2 + 3\ H_2O$

$NH_4^+ + 2\ O_2 + H_2O \text{-->} NO_3^- + 2\ H_3O^+$

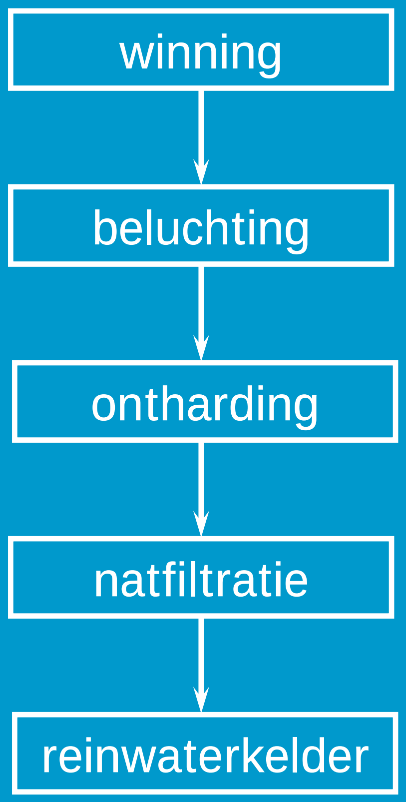
# Diep anaëroob grondwater

| Parameter | Eenheid | Ruwwater | Reinwater |
|---|---|---|---|
| Temperatuur | °C | 10,5 | 10,5 |
| pH | - | 6,9 | 7,6 |
| EGV | mS/m | 51 | 48 |
| SI | - | -0,04 | 0,2 |
| Troebelheid | FTU | - | <0,1 |
| $Na^+$ | mg/l | 23 | 21 |
| $K^+$ | mg/l | 3 | 3 |
| $Ca^{2+}$ | mg/l | 82 | 77 |
| $Mg^{2+}$ | mg/l | 5,2 | 6,3 |
| $Cl^-$ | mg/l | 41 | 41 |
| $HCO_3^-$ | mg/l | 267 | 241 |
| $SO_4^{2-}$ | mg/l | 18 | 21 |
| $NO_3^-$ | mg/l | 0,07 | 1,6 |
| $O_2$ | mg/l | 0 | 10,7 |
| $CH_4$ | mg/l | 2 | <0,05 |
| $CO_2$ | mg/l | 63 | 11 |
| $Fe^{2+}$ | mg/l | 8,8 | 0,04 |
| $Mn^{2+}$ | mg/l | 0,3 | <0,01 |
| $NH_4^+$ | mg/l | 2,2 | <0,01 |
| DOC | mg/l | 7 | 6 |
| E-Coli | n/ 1000 ml | 0 | 0 |
| Bentazon | µg/l | - | - |
| Chloroform | µg/l | - | - |
| Bromaat | µg/l | - | - |

Pompstation St. Jansklooster

# Grondwaterzuivering met ontharding

zuiveringsschema

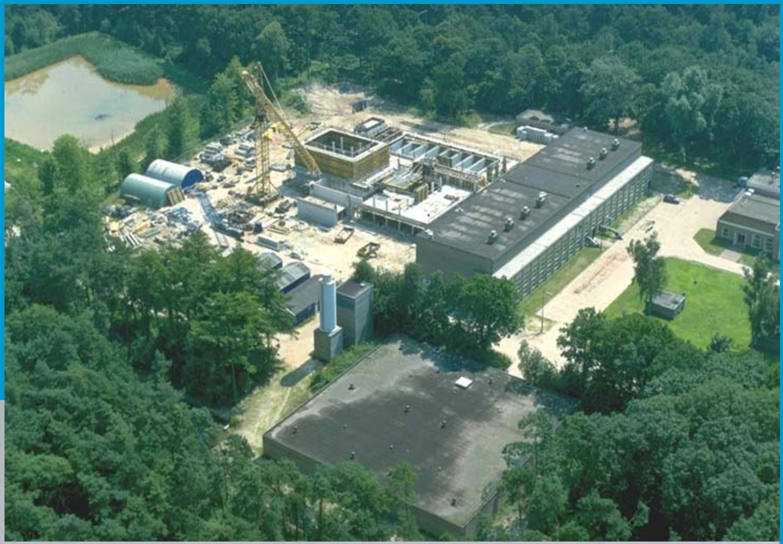


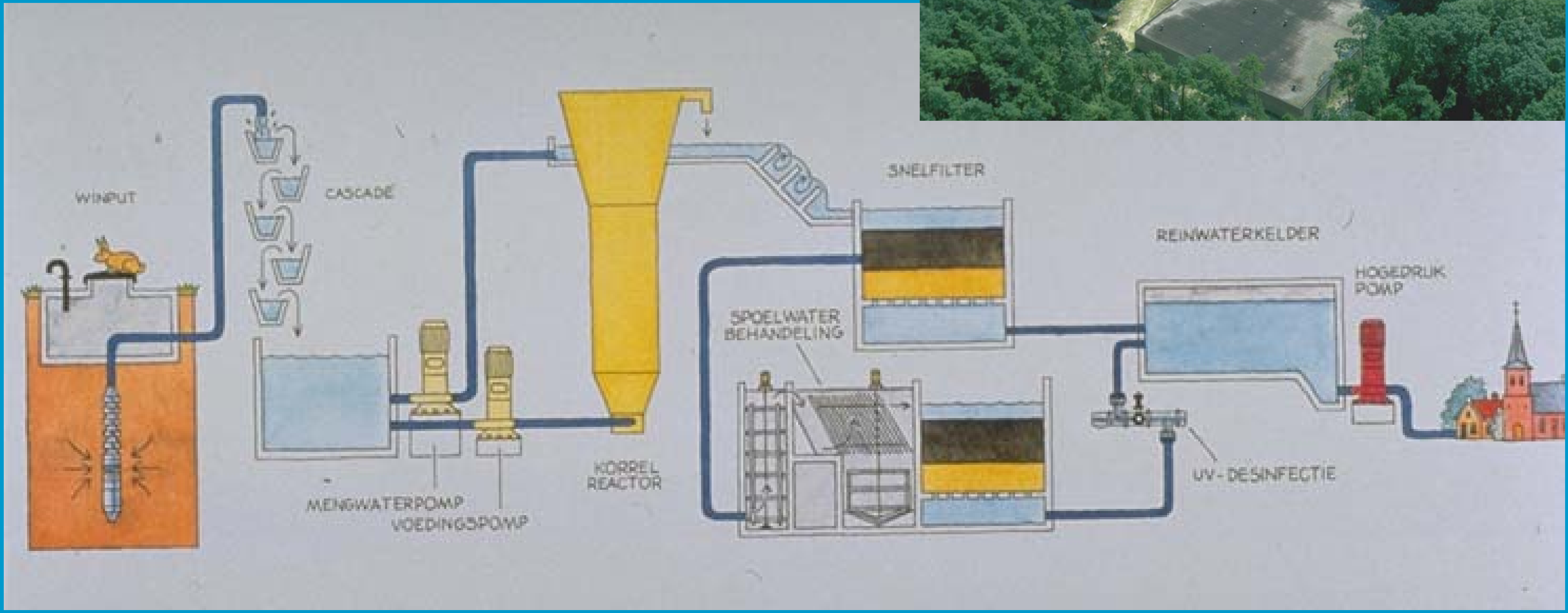

Kenmerken grondwaterzuivering met ontharding:

- hoge hardheid

$NaOH + Ca^{2+} + HCO_3^- \text{-->} CaCO_3 + Na^+ + H_2O$
$Ca(OH)_2 + Ca^{2+} + 2\ HCO_3\text{-} \text{-->} 2\ CaCO_3 + 2\ H_2O$

# Pompstation Seppe





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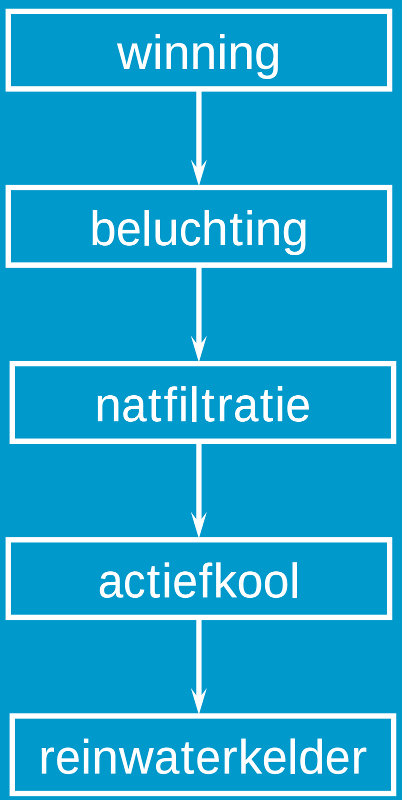
# Grondwaterzuivering met actief koolfiltratie

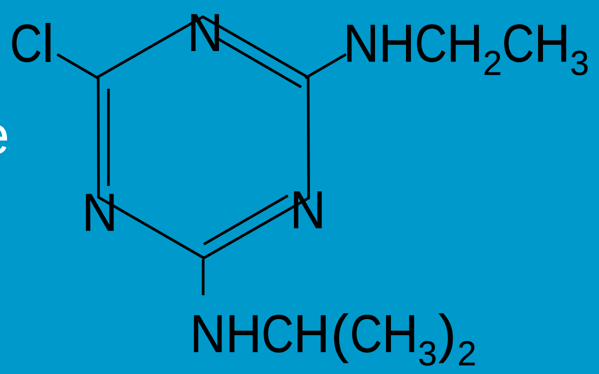
zuiveringsschema




Kenmerken grondwaterzuivering met actief koolfiltratie:

- bestrijdingsmiddelen
- geur, smaak, kleur

atrazine



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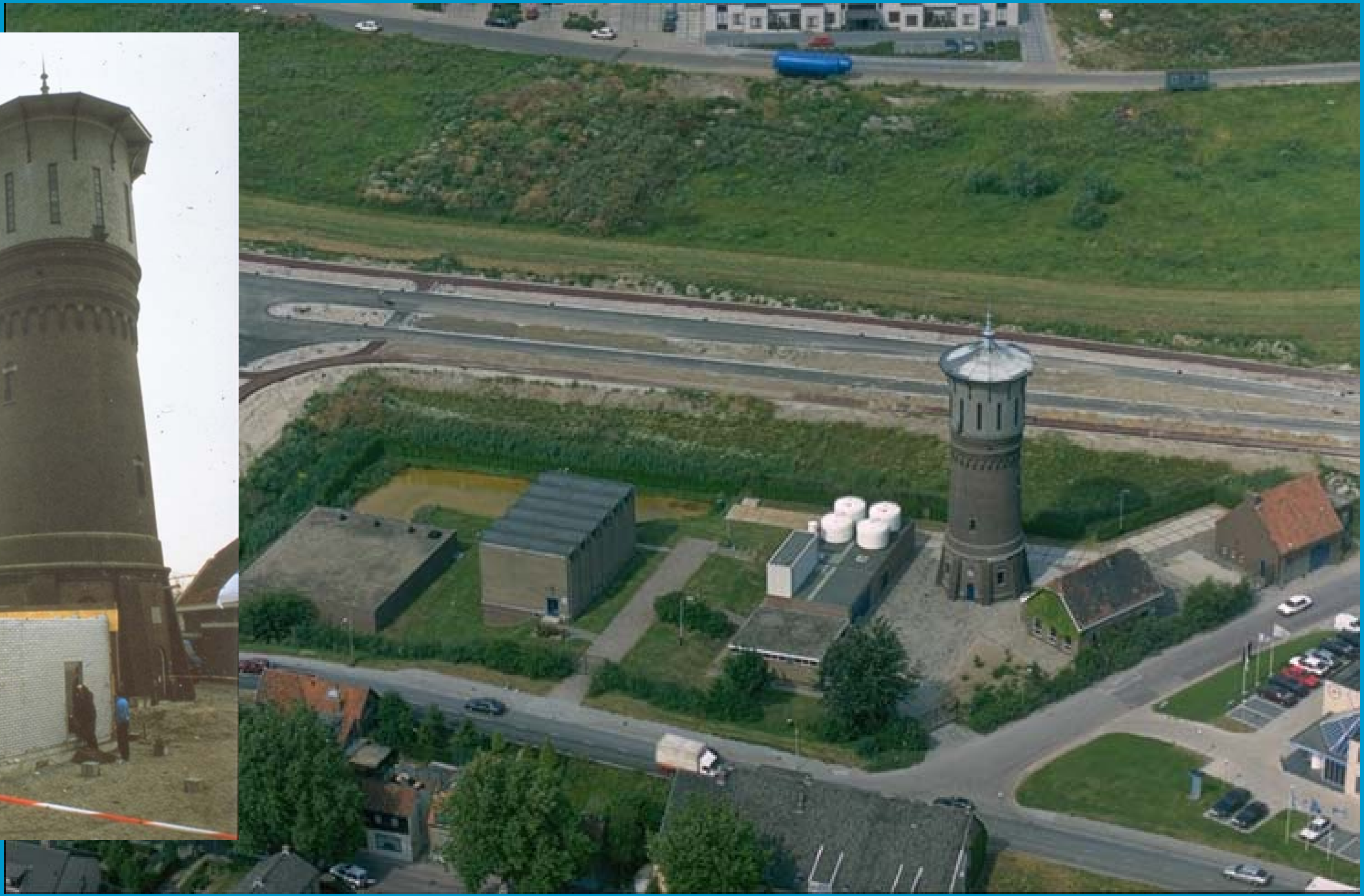
# Pompstation Hendrik Ido Ambacht



# Oevergrondwater



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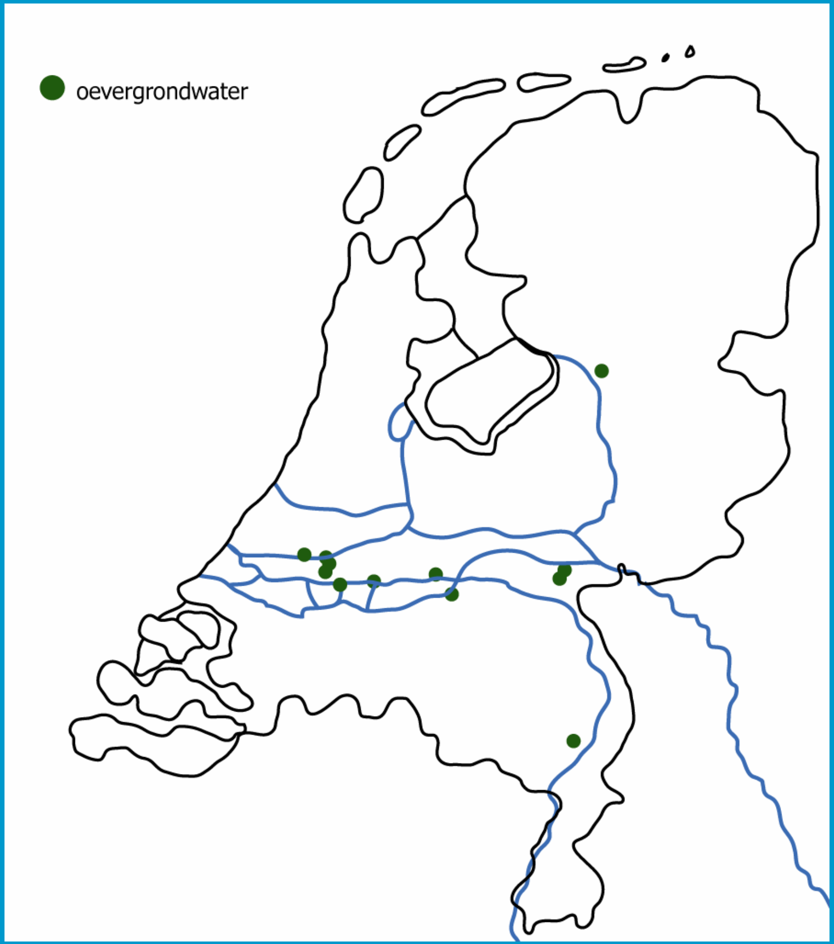
# Oevergrondwater locaties



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# Kenmerken oevergrondwater

**Voordelen**

- voldoende beschikbaarheid
- geringe kwetsbaarheid
- hygiënisch betrouwbaar
- gelijkmatige samenstelling
- biologisch en chemisch stabiel

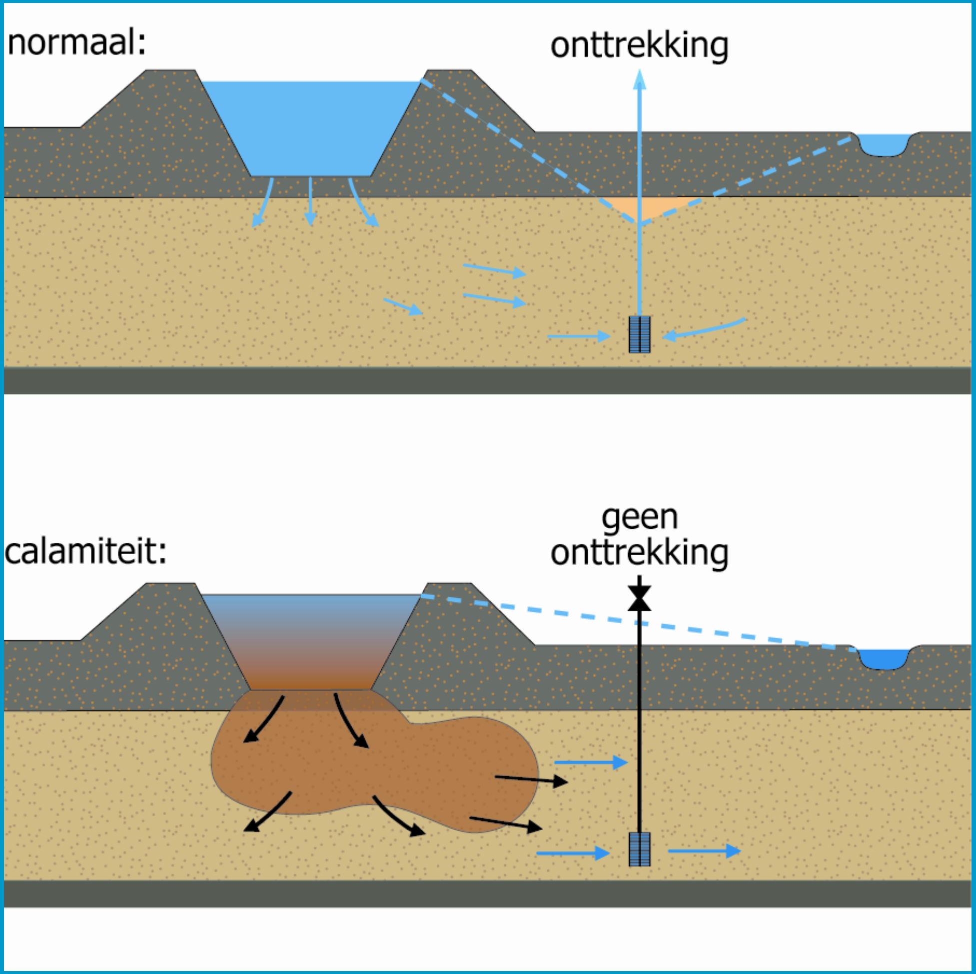
**Nadelen**

- continue belasting oppervlaktewater en landbouw
- zoutbelasting Rijn
- putverstoppingen en zettingen

**Opzet infrastructuur**

- gering ruimtebeslag
- grote transportafstand

# Historische vergissing?



# Sandozramp

| | |
|---|---|
| 1 november 1986 | brand Sandoz<br>in Rijn geloosd 10 - 30 ton BM |
| november 1986 | visbestand tot Mainz volledig vernietigd<br>insectenlarven volledig en kreeftachtigen gedeeltelijk vernietigd<br>drinkwaterinname buiten bedrijf |
| medio november 1986 | microbiologische activiteit hersteld<br>drinkwaterinname overal hervat |
| voorjaar 1987 | visbestand gedeeltelijk hersteld |
| najaar 1987 | geen negatieve gevolgen meer |



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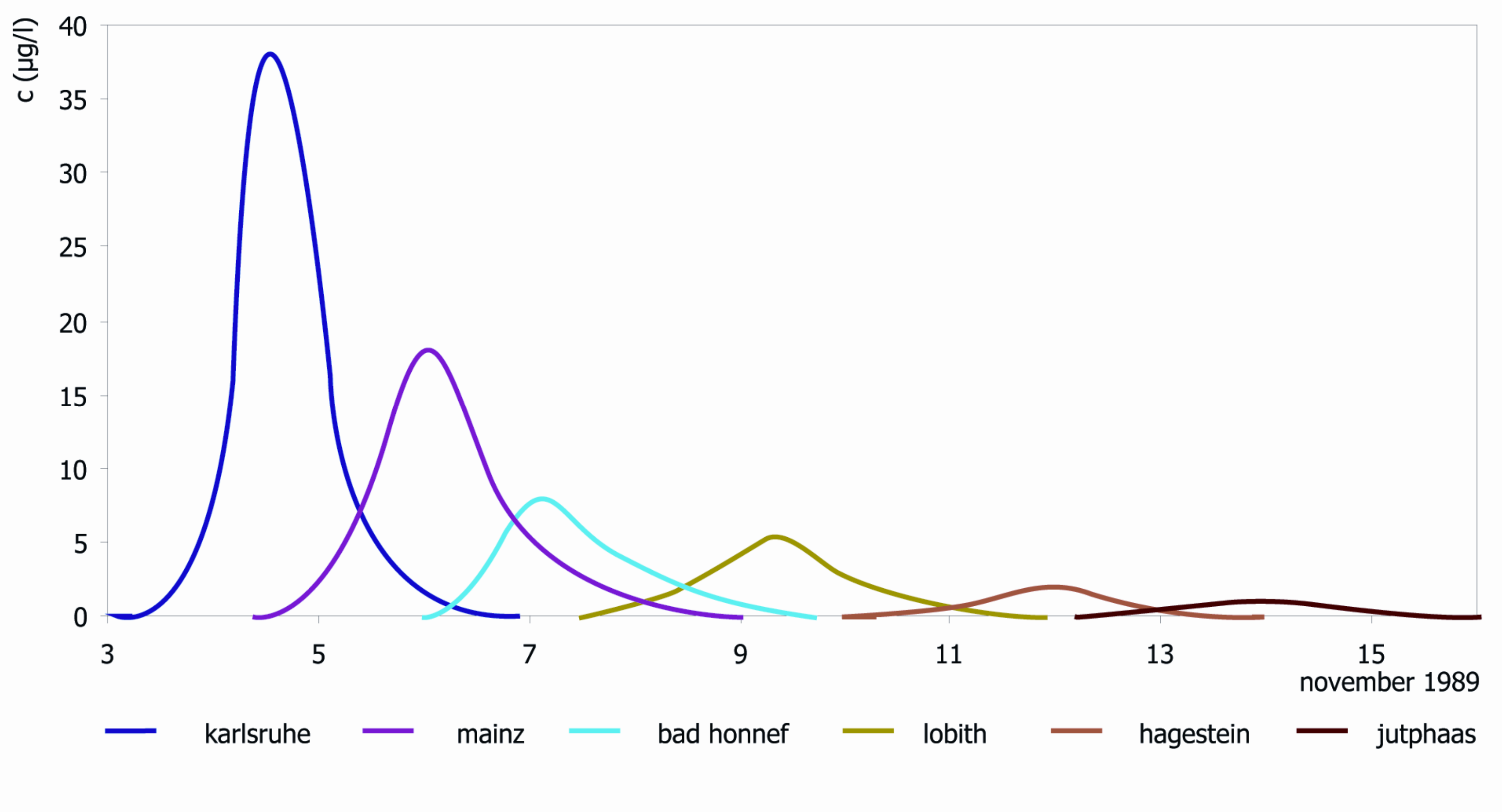
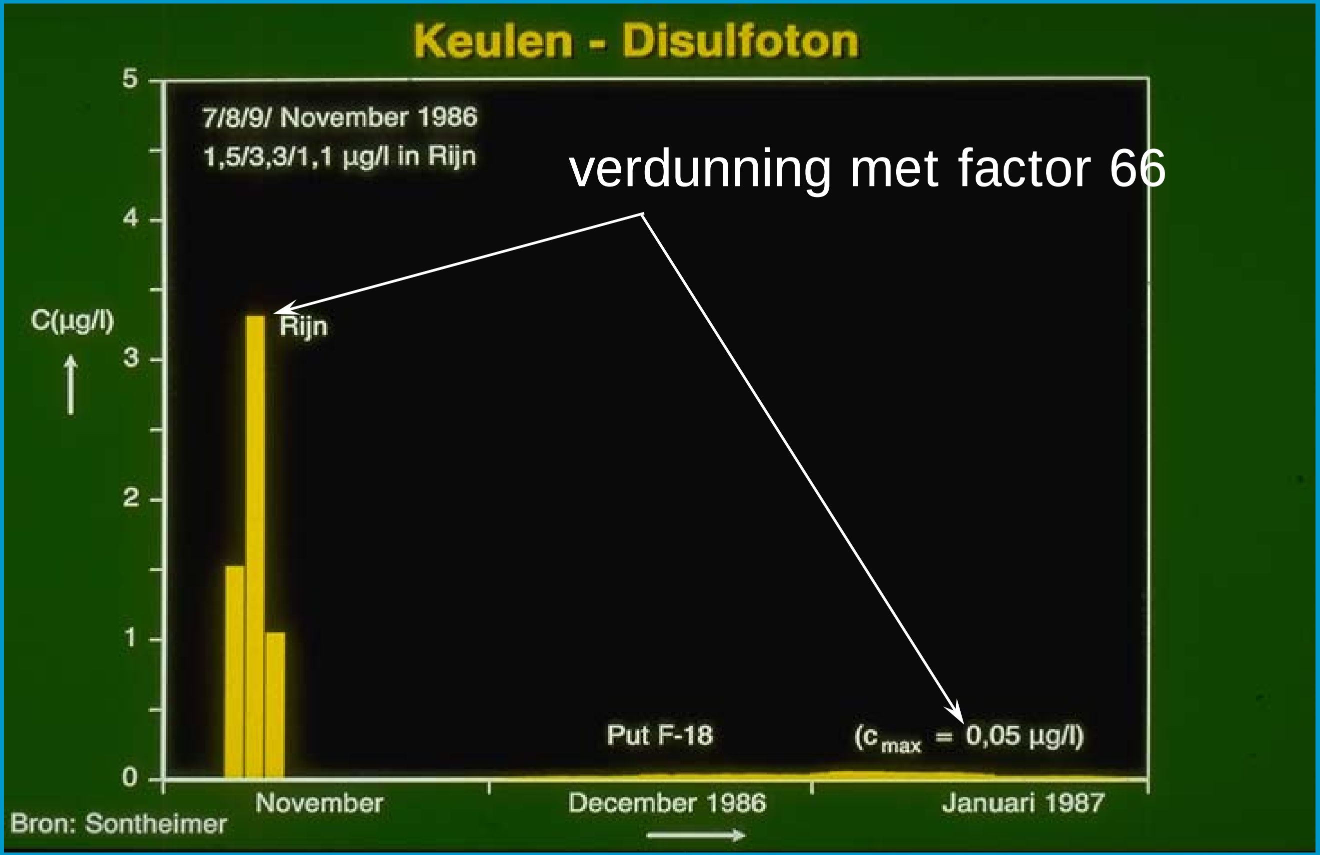
# Sandozramp


c (µg/l)
40
35
30
25
20
15
10
5
0
3
5
7
9
11
13
15
november 1989
karlsruhe
mainz
bad honnef
lobith
hagestein
jutphaas

# Afvlakking oevergrondwater

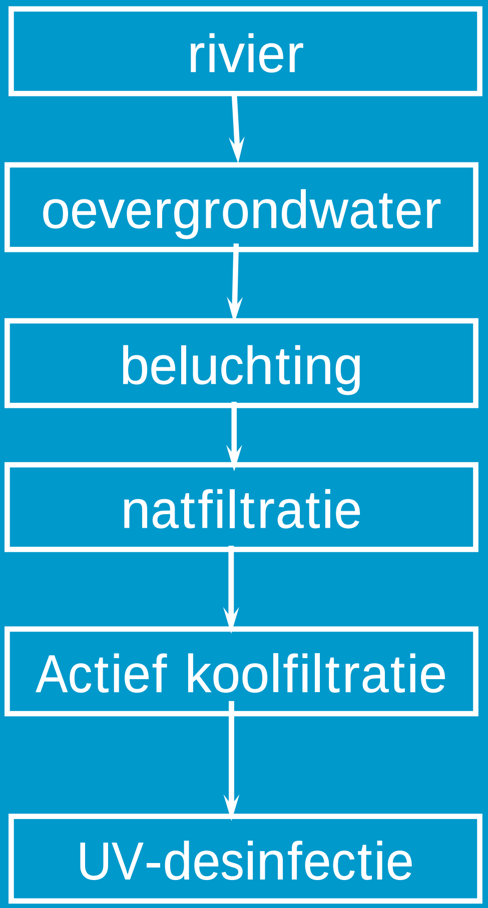



Moraal:

Und die Moral von der Geschicht

Die stoßbelasting stört uns nicht

# Zuivering oevergrondwater




Oevergrondwater
verwijdering micro-organismen, afvlakking, afbraak, chemische en biologische stabiliteit

Beluchting:
toename zuurstof, verwijdering $CH_4$

Natfiltratie:
verwijdering mangaan, ammonium, ijzer

Actief koolfiltratie
verwijdering bestrijdingsmiddelen

UV-desinfectie:
afsterven micro-organismen

# Oevergrondwater met ammonium en pesticiden

| Parameter | Eenheid | Ruwwater | Reinwater |
|---|---|---|---|
| Temperatuur | °C | 12 | 12 |
| pH | - | 7,3 | 7,4 |
| EGV | mS/m | 78,4 | 77 |
| SI | - | -0,1 | -0,1 |
| Troebelheid | FTU | - | <0,1 |
| $Na^+$ | mg/l | 69 | 70 |
| $K^+$ | mg/l | 4 | 4 |
| $Ca^{2+}$ | mg/l | 84 | 84 |
| $Mg^{2+}$ | mg/l | 12 | 12 |
| $Cl^-$ | mg/l | 128 | 135 |
| $HCO_3^-$ | mg/l | 223 | 187 |
| $SO_4^{2-}$ | mg/l | 55 | 59 |
| $NO_3^-$ | mg/l | <0,1 | 2,3 |
| $O_2$ | mg/l | 0,8 | 5,7 |
| $CH_4$ | mg/l | 1 | <0,05 |
| $CO_2$ | mg/l | 20 | 14 |
| $Fe^{2+}$ | mg/l | 3,8 | 0,02 |
| $Mn^{2+}$ | mg/l | 0,9 | <0,01 |
| $NH_4^+$ | mg/l | 3 | <0,03 |
| DOC | mg/l | 3 | 2,5 |
| E-Coli | n/ 1000 ml | 0 | 0 |
| Bentazon | µg/l | 0,32 | <0,05 |
| Chloroform | µg/l | - | - |
| Bromaat | µg/l | - | - |

Pompstation De put

# Iron removal at groundwater pumping station Harderbroek

**Karin Teunissen**
**25 May 2007**
**08 October 2007**

# Iron removal at groundwater pumping station Harderbroek

## Committee

Prof. ir. J.C. van Dijk
Dr. ir. L.C. Rietveld
Dr. ir. A.J. Abrahamse
H. Leijssen
Prof. dr. ir. M.C.M. van Loosdrecht

# Content

## Introduction

- Harderbroek
- Iron removal
- Objective

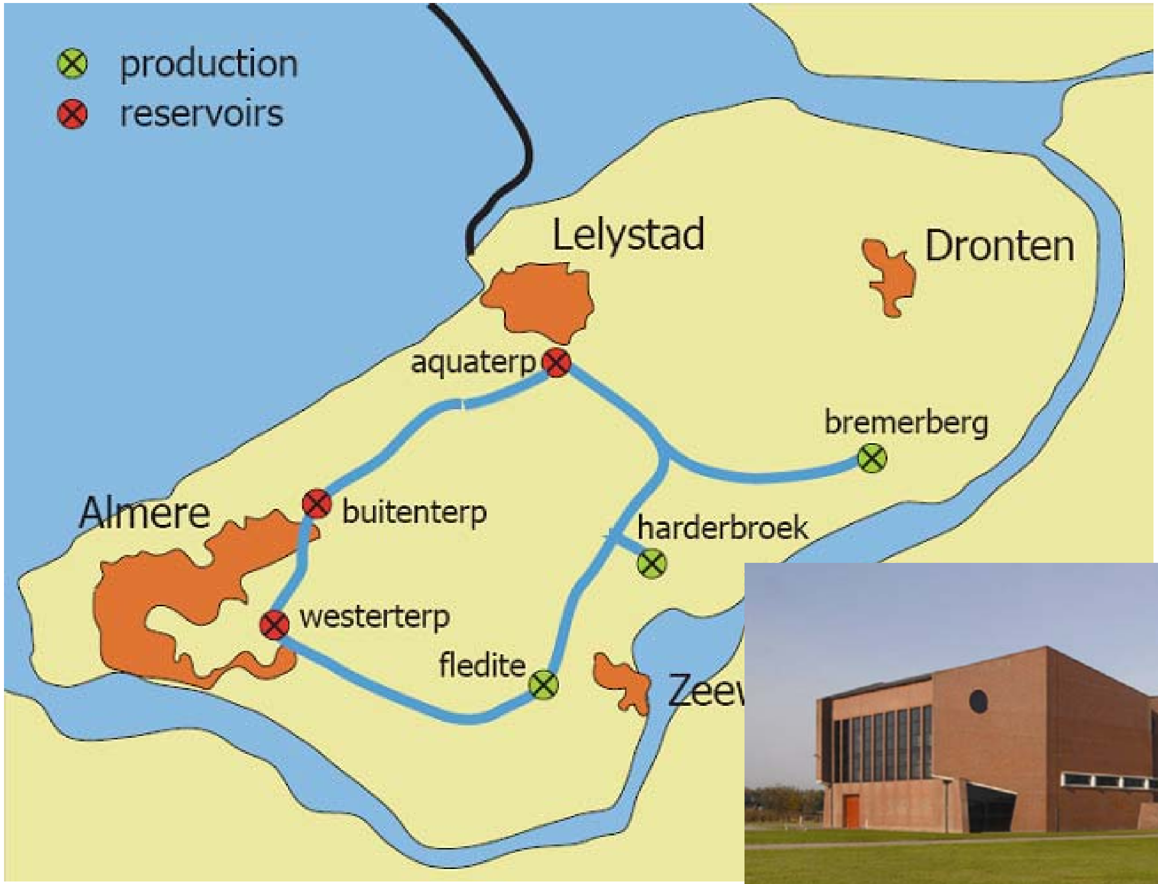
## Research

- Fingerprint
- Column experiments
- Model

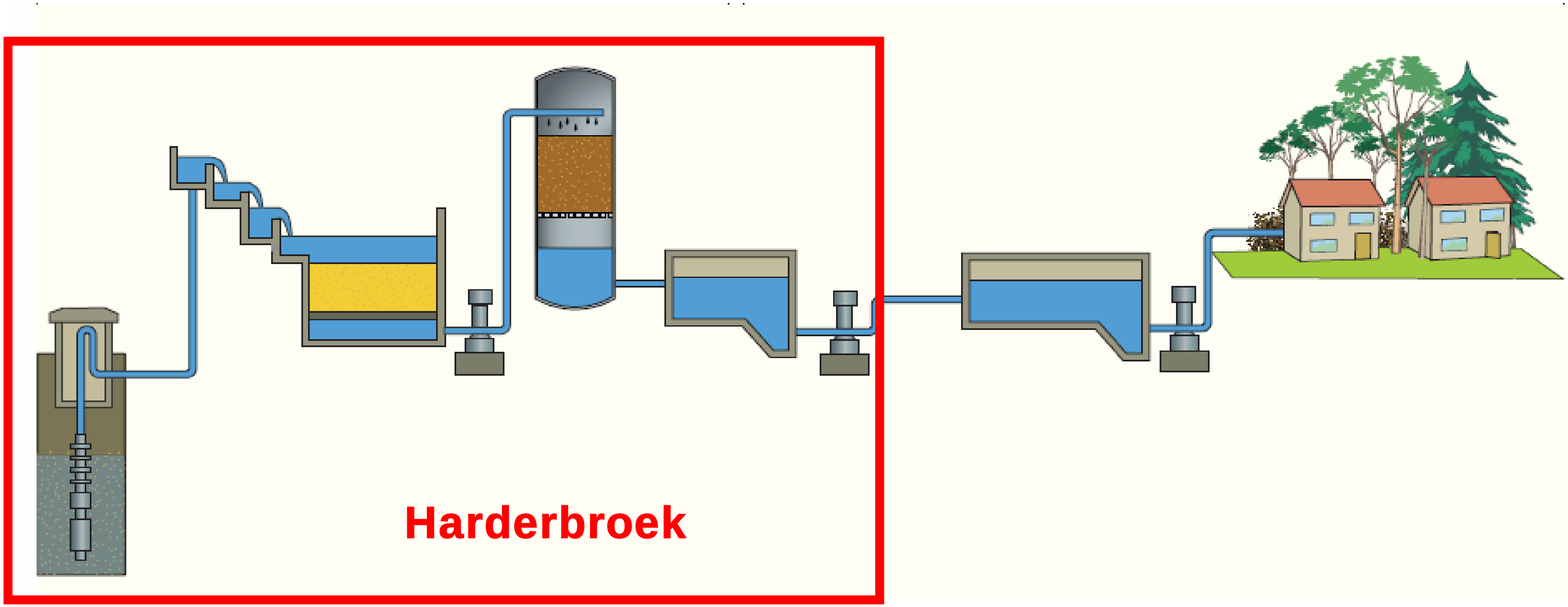
## Conclusions and recommendations

# HARDERBROEK

# Drinking water supply Flevoland




# Treatment scheme Harderbroek

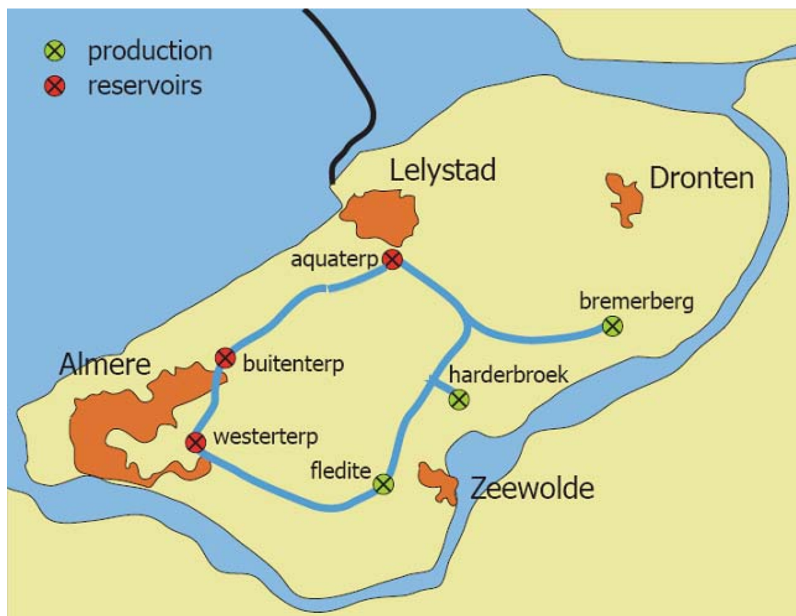


# IRON REMOVAL

# Iron removal

## Iron is removed to avoid iron deposits

- In distribution system
- In laundry
- In drinking water




# Iron in groundwater

**$Fe^{2+}$**

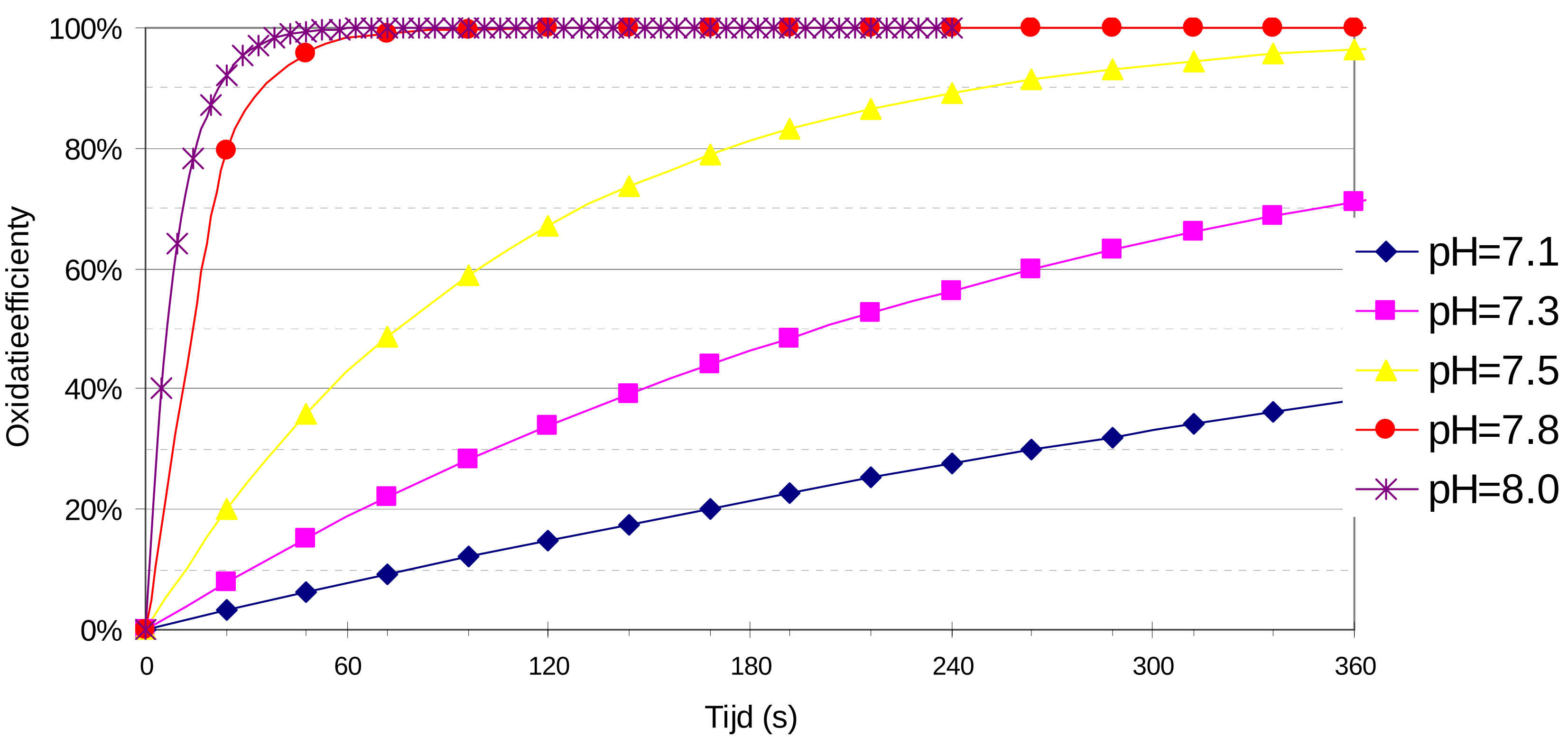
- Present in anaerobic groundwater
- Dissolved in water

**$Fe^{3+}$**

- Forms iron flocks in water
- Gives brownish colour to the water

# Iron Removal

**Iron oxidation:** $Fe^{2+}$ + oxygen → $Fe^{3+}$



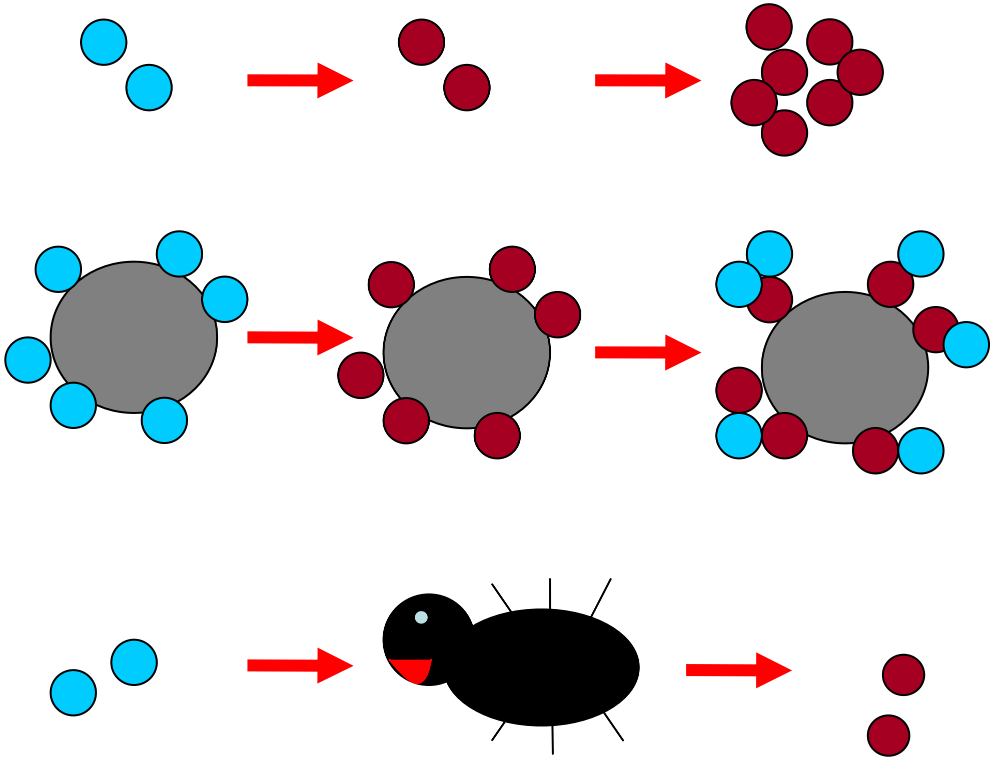
# Iron removal


## Iron removal mechanisms:

**Flock filtration iron removal**

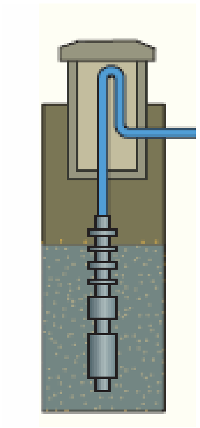
**Adsorptive iron removal**

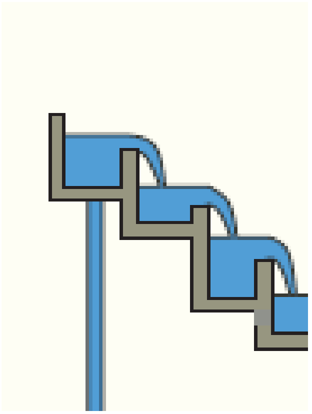
**Biological iron removal**

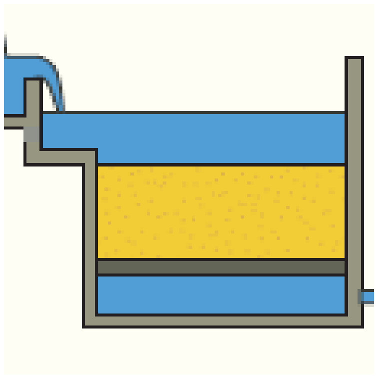


# Iron Removal

$Fe^{2+}$ $O_2$ $Fe^{3+}$



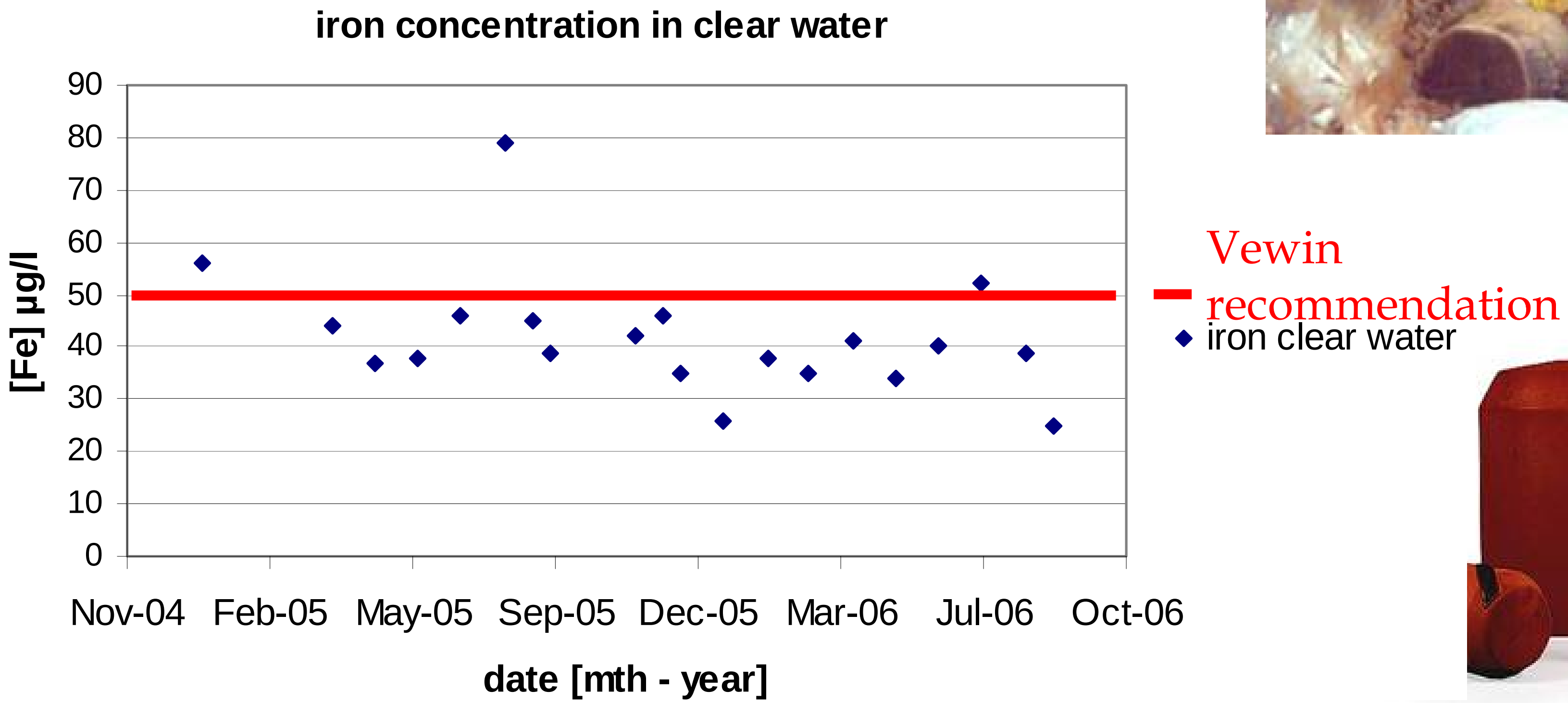




# OBJECTIVE

# Situation at Harderbroek

**Expensive cleaning events**



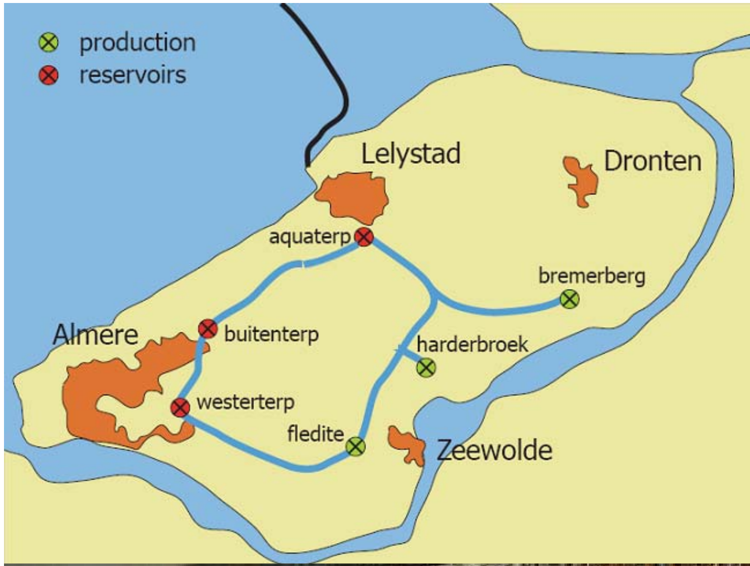

# Harderbroek vs Fledite

**Comparable water source**

**Same filters**

**Different aeration**

- **Harderbroek cascade aeration**
- **Fledite spray aeration**




## Hypothesis (1)

**Formed iron hydroxide flocks breakdown in cascade or filter inlet construction**

**Small flocks break through the filters**

# Methods

## Particle fingerprint

- To identify the presence of particles through the treatment plant in relation to operational events

## Column experiments

- To get information on oxidation and flock formation

## Model

- Generate insight in processes in the filter
- Elaborate future scenarios

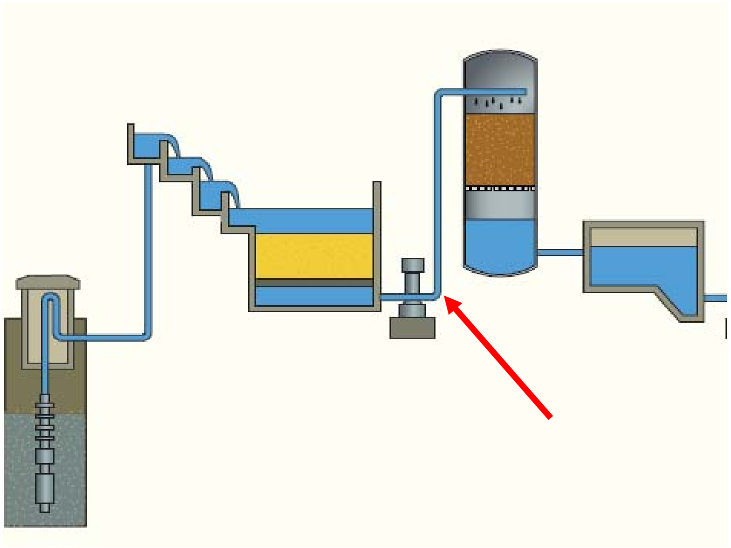
# FINGERPRINT

# Fingerprint

## Particles identified with particle counters

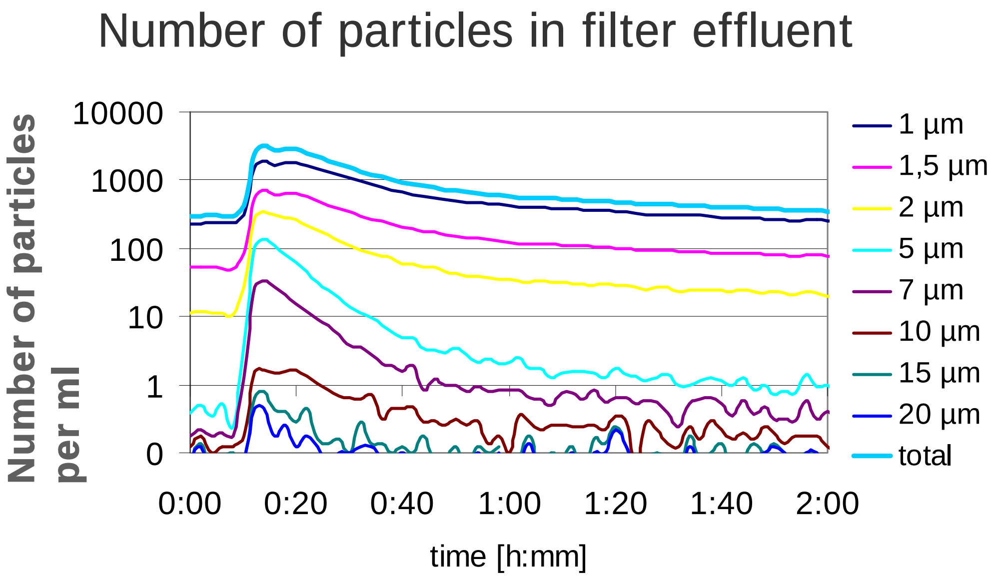
## Mainly focussed on filtration step

- After switching a filter
- After a backwash



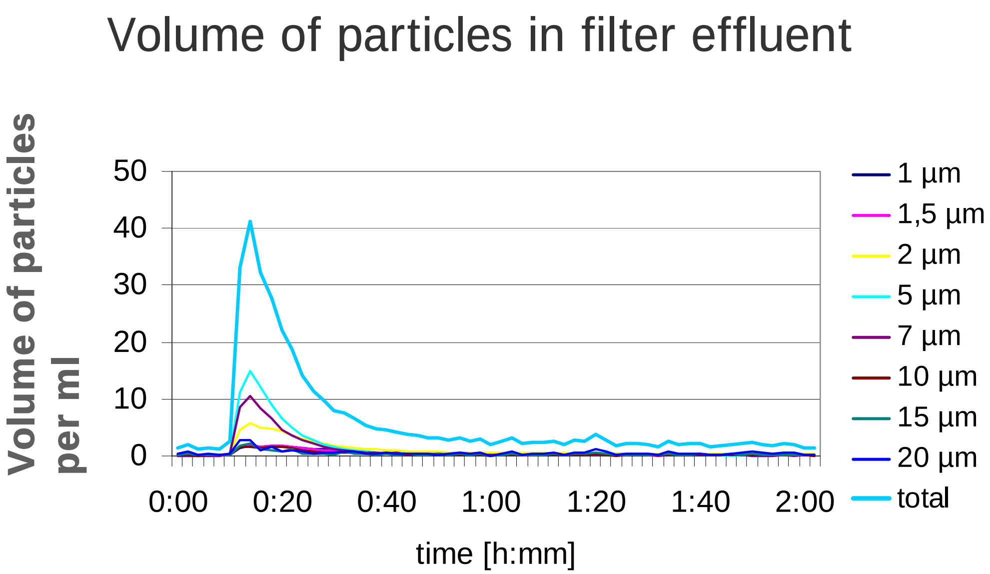
# Fingerprint results

## After filter switch




## ppb

$$V = \frac{1}{6}\pi\sqrt{d_i \cdot d_j}^3 \cdot number$$




**1 part per billion =**

**1 volume of particles in**

**1,000,000,000 volumes of water**

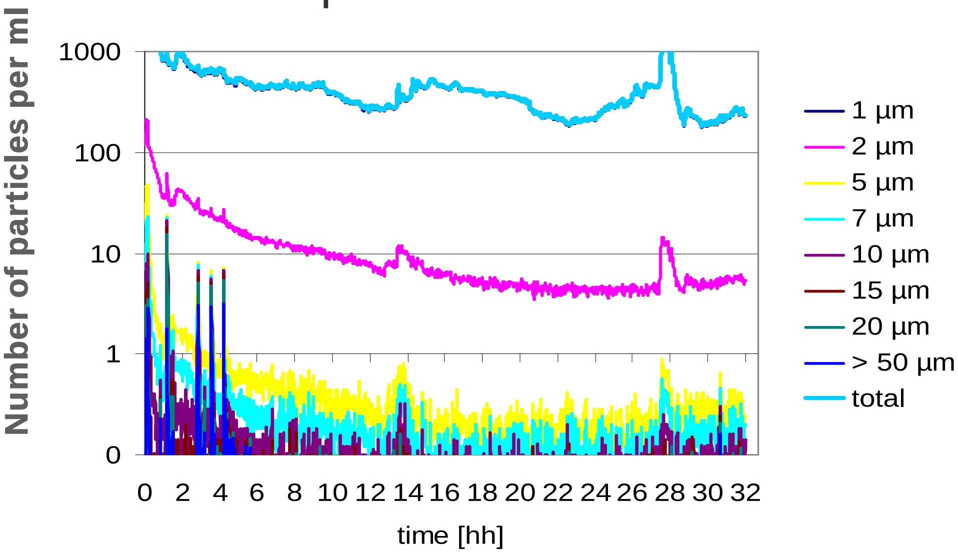
# Fingerprint results

## After backwash

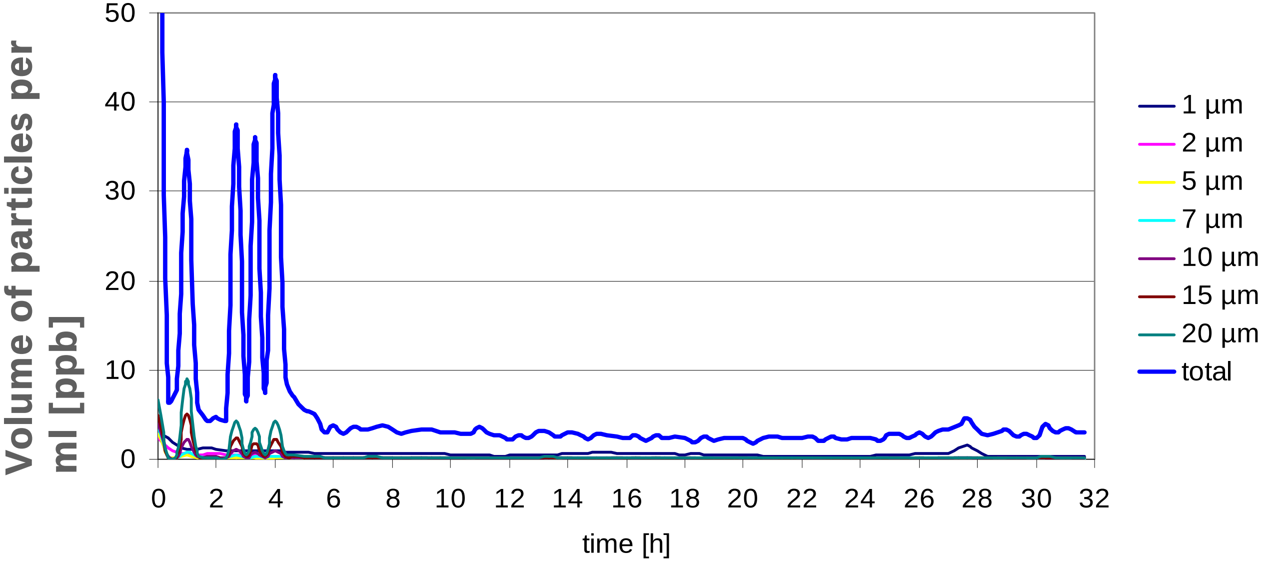
**Volume concentration increased for 4 hours**

**→ recirculation**

Number of particles in filter effluent



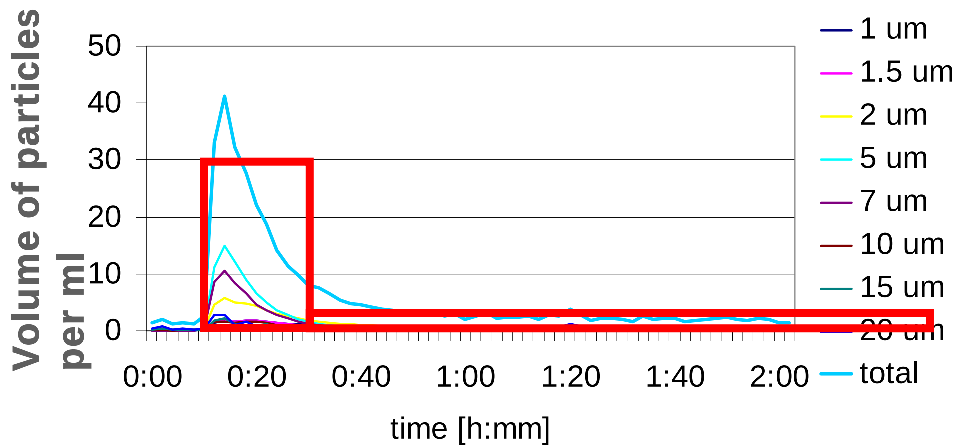

Volume of particles in filter effluent



# Fingerprint

## Volume load by events compared to stable operation

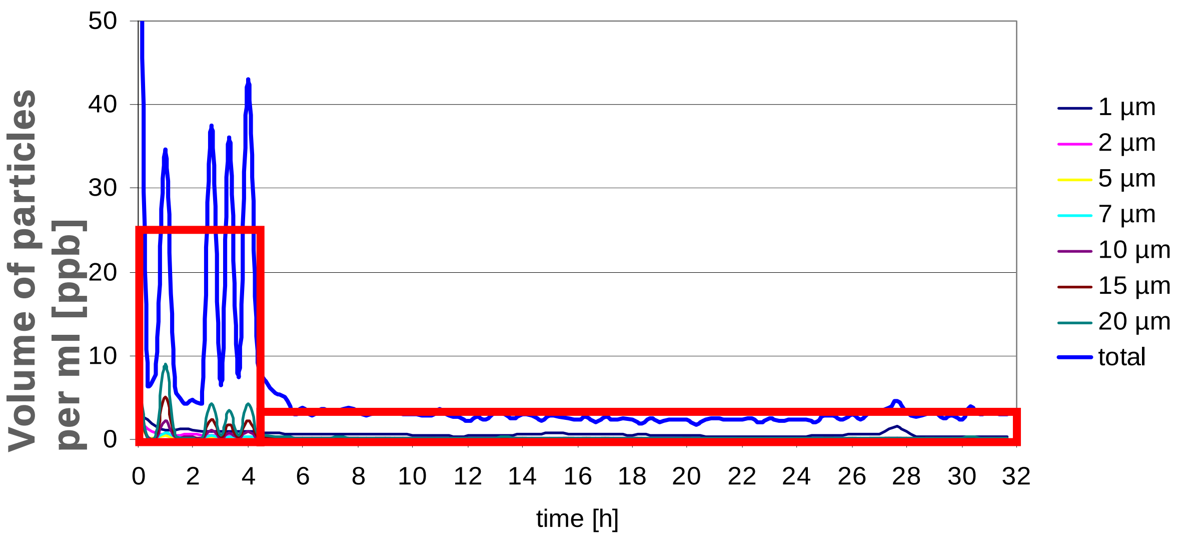
Volume of particles in filter effluent




### Switch filter

**In 2 % of the time**
**15 % of the load**

Volume of particles in filter effluent




### Backwash filter

**In 13 % of the filter run time 45 % of the volume load**

# Fingerprint

**Aim**

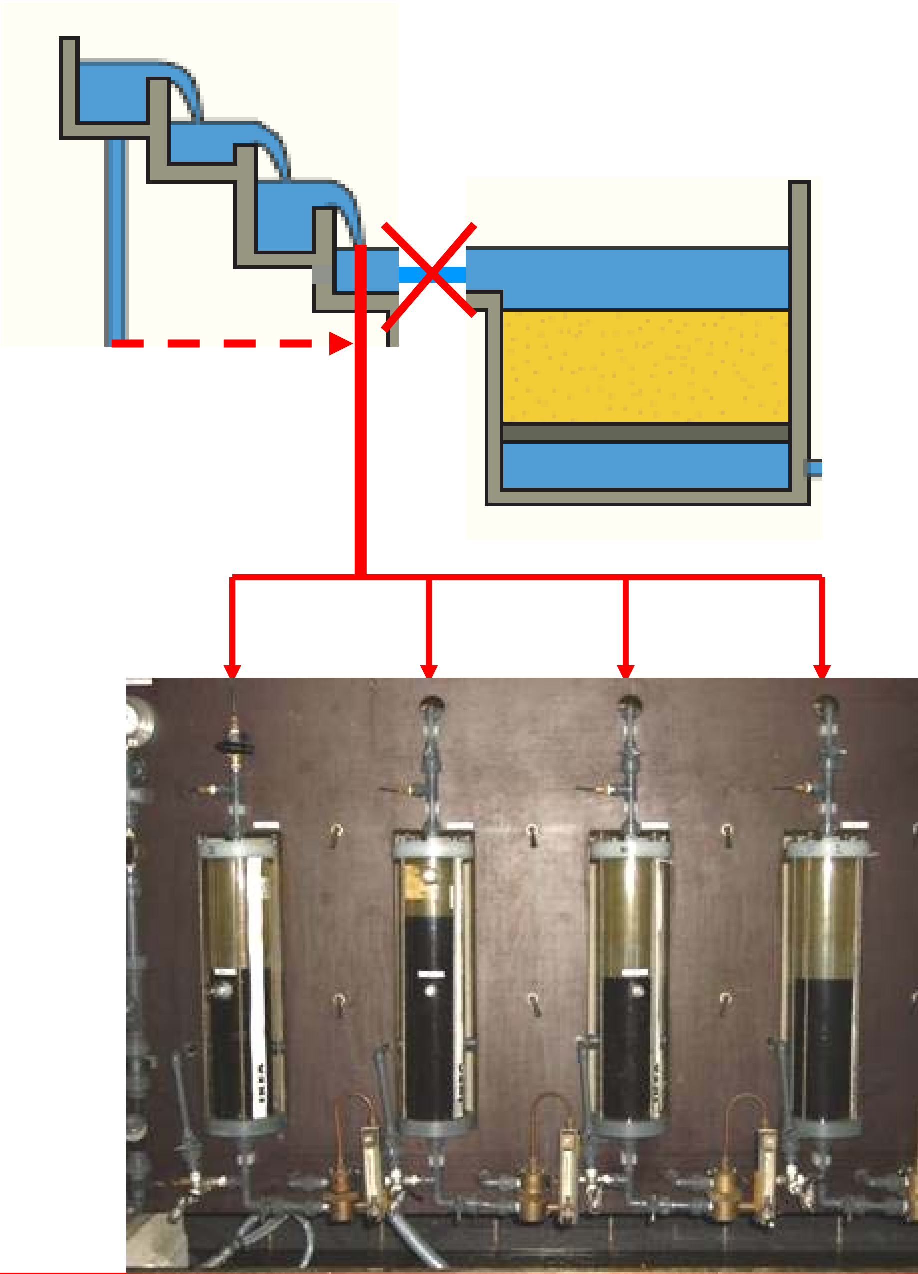
**Average 1 ppb**

**Reduce peaks**

| Pumping station | Average ppb clear water | Cleaning frequency |
|---|---|---|
| Harderbroek | 5 | 1 in 3 years |
| Franeker | 15 | 1 in 1 year |
| Franeker + UF | 1 | 1 in 10 - 12 years (expected) |

# COLUMN EXPERIMENTS

# Column experiments



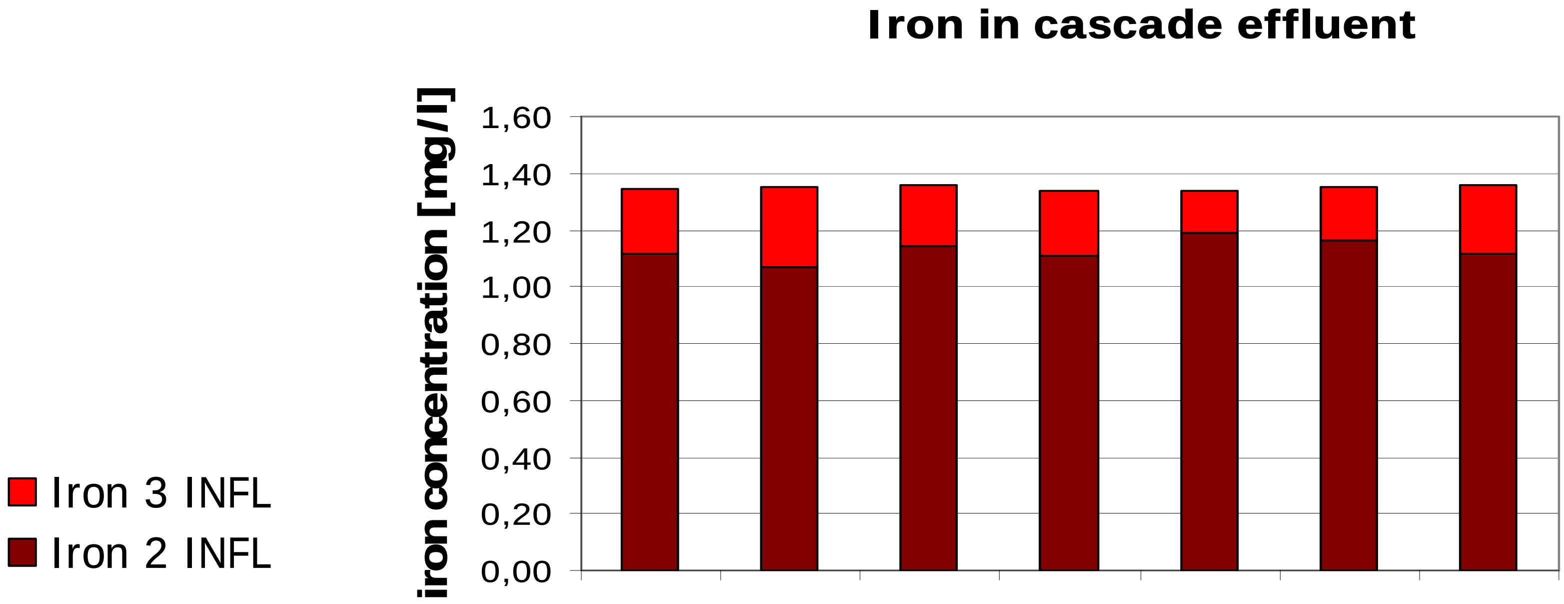
**Part 1**

- mixing intensity
- residence time
- and aeration

**Part 2**

- pH

# Column results




## Hypothesis (2)

**pH in cascade effluent water too low for efficient oxidation**

# Column experiments

## Experiments with pH increase

**NaOH dosage**

pH from 7.5 to 8.0

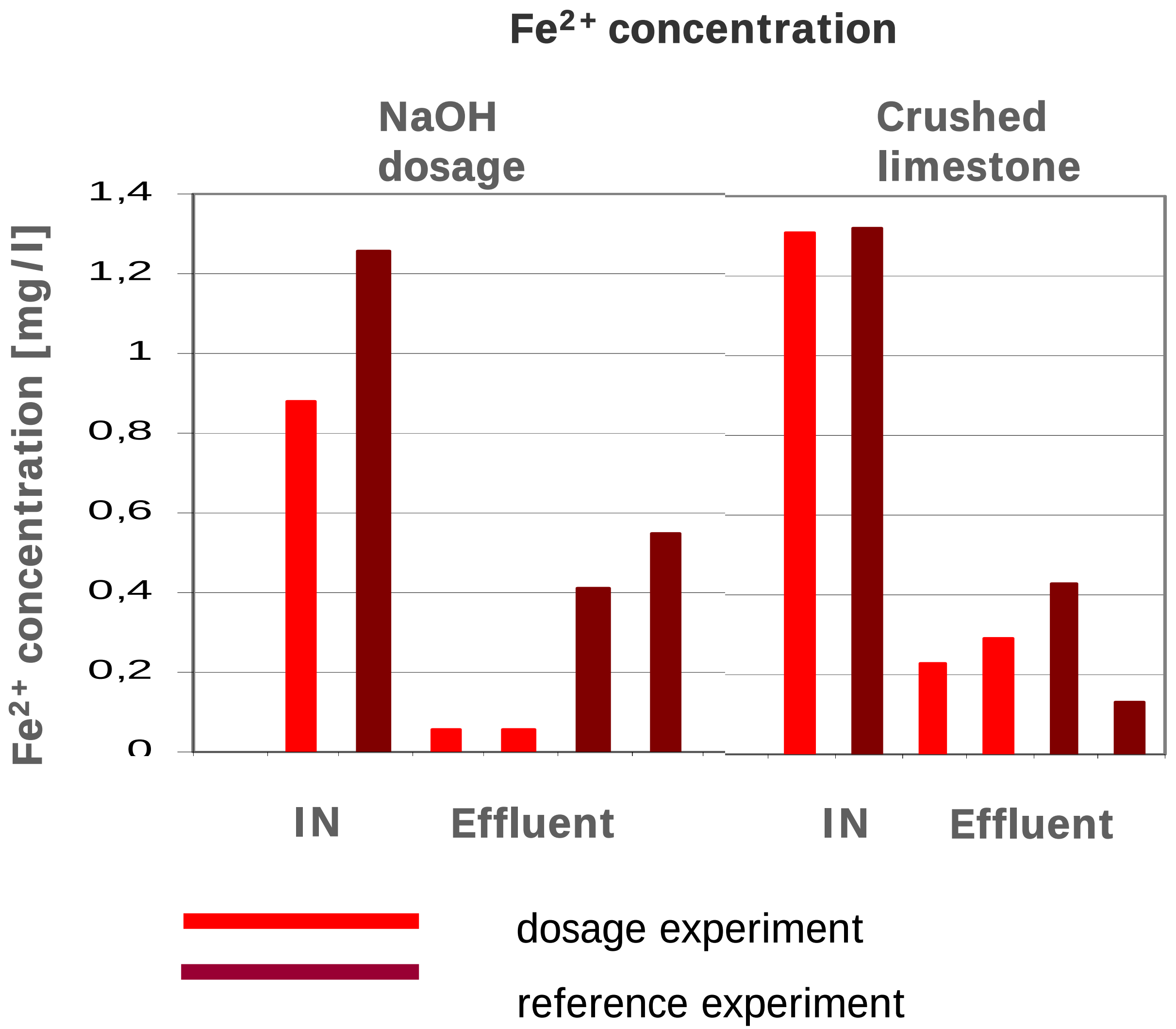
**Crushed limestone filtration**

pH from 7.5 to 7.7

# Column results

## Results

**decrease $Fe^{2+}$ concentration**



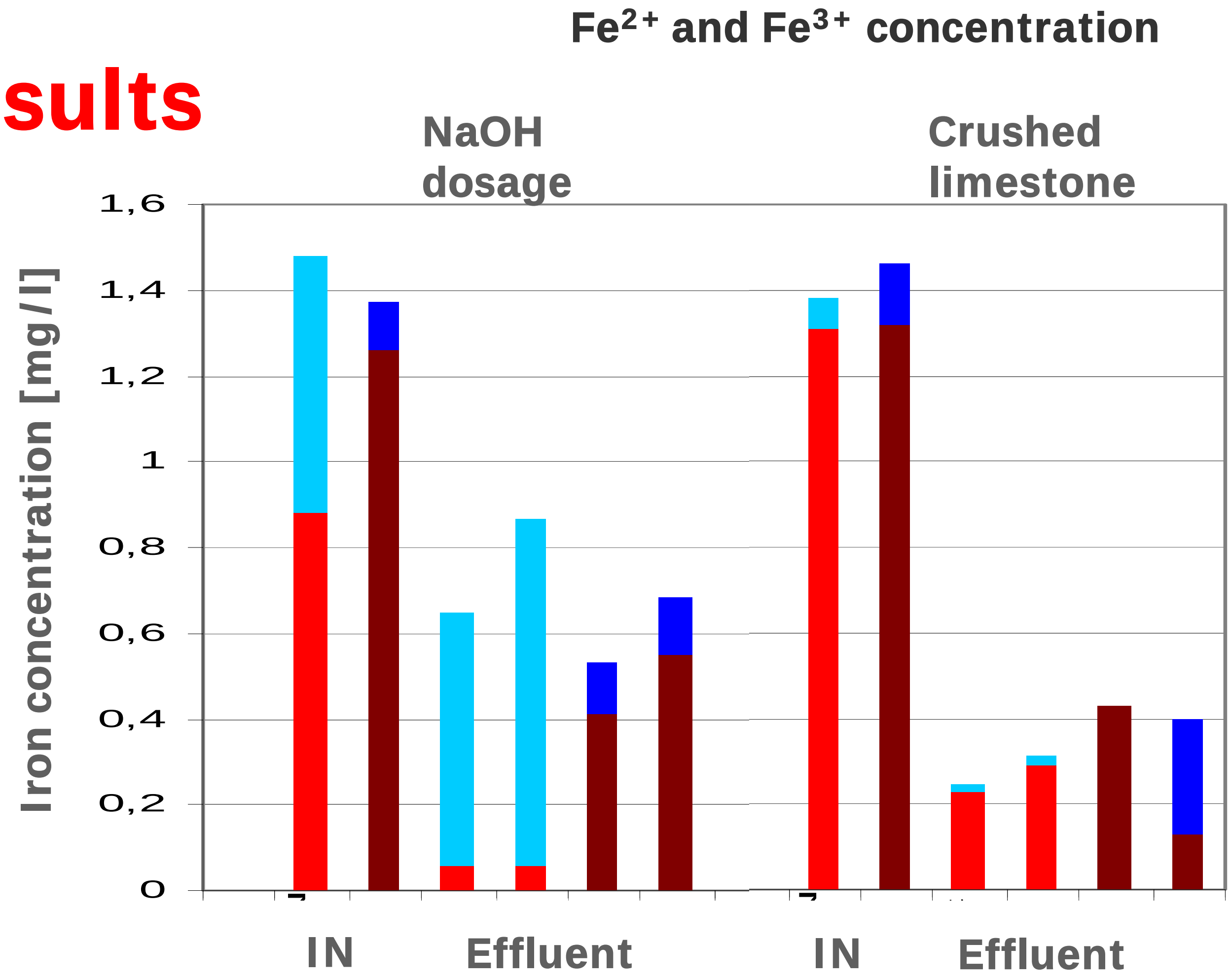
# Column results

## Results

**Decrease $Fe^{2+}$ concentration**

**Increase $Fe^{3+}$ concentration**

**Total iron removal comparable**




$Fe^{2+}$ dosage experiment

$Fe^{2+}$ reference experiment

$Fe^{3+}$ dosage experiment

$Fe^{3+}$ reference experiment

# MODEL

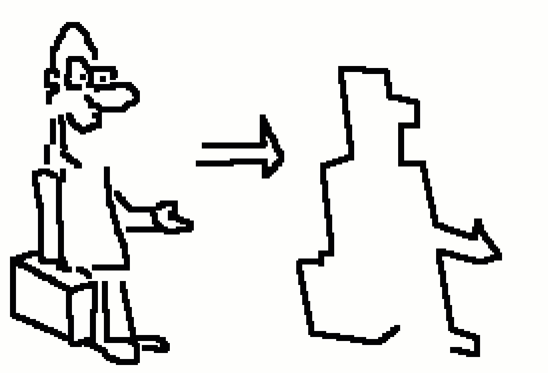
# Model

## Modelling

**Reflection of reality**

**Simplification of reality**

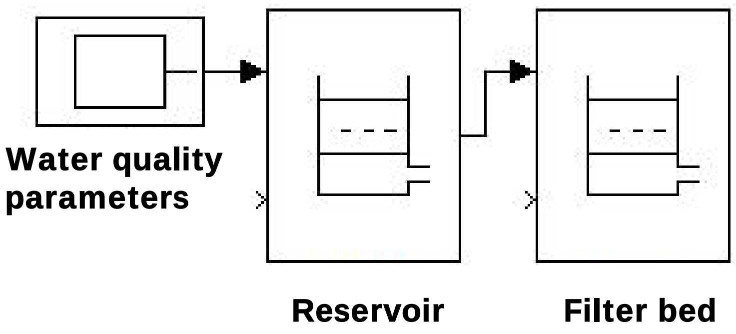
**Easy and fast method to vary parameters**



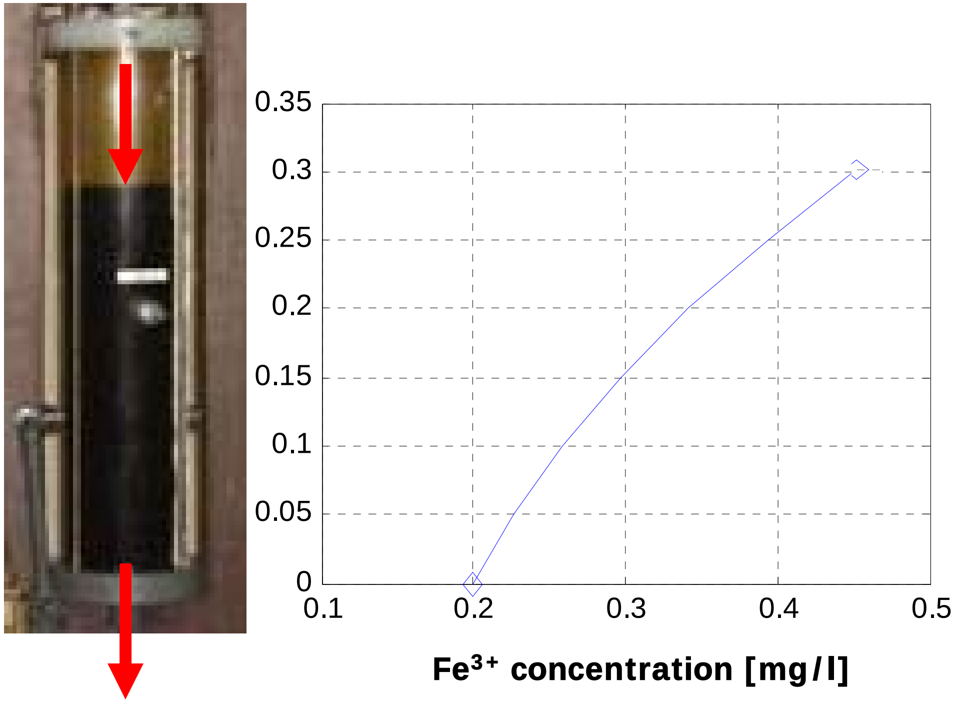
# Model

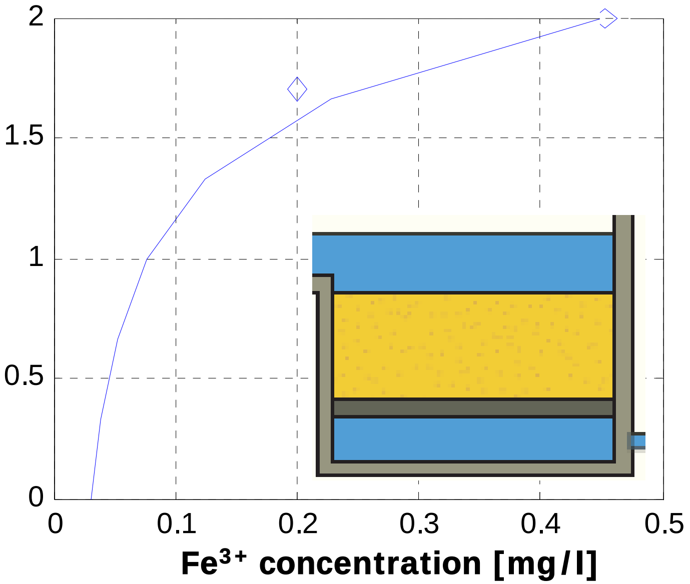
## Iron removal model is created in Stimela

- First reservoir represents water phase before filter
  - Flock formation
  - No flock removal
  - No adsorption
- Filter represents filter bed
  - Flock formation
  - Flock removal
  - Adsorptive iron removal



# Model results




**Column height 30 cm**

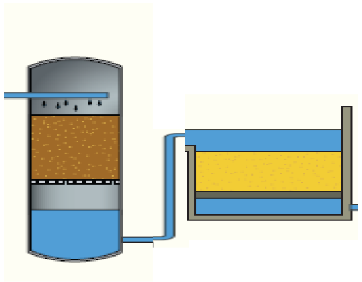
**$Fe^{3+}$ influent concentration 0.45 mg/l**
**$Fe^{3+}$ effluent concentration 0.20 mg/l**

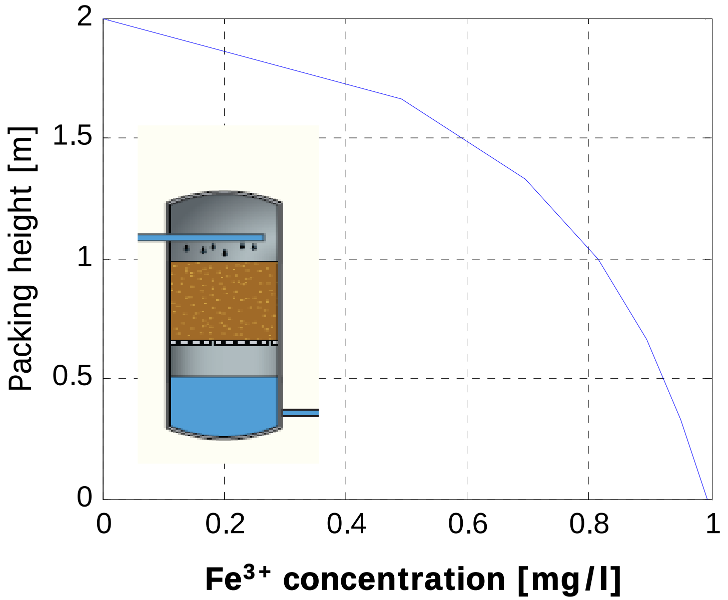
**Filter bed height 2 m**

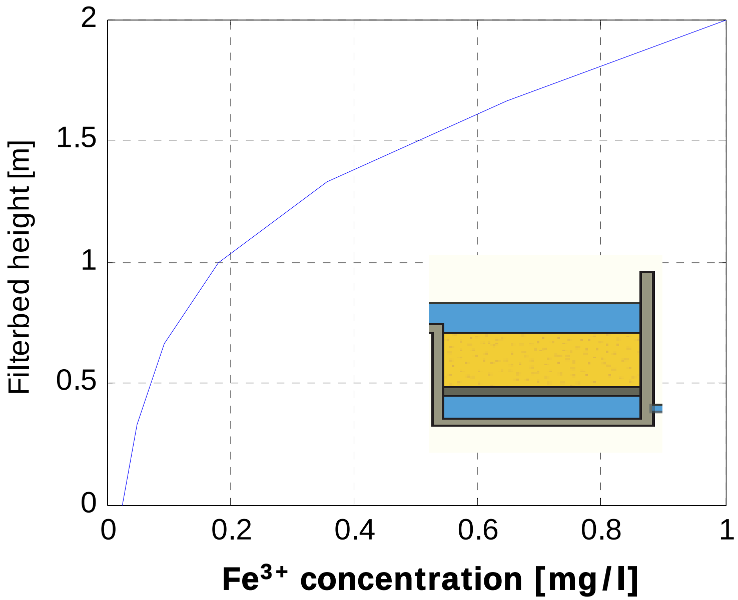
**$Fe^{3+}$ effluent concentration 0.033 mg/l**

# Model results

## Tower aeration before filtration:






**$Fe^{3+}$ effluent concentration**

**1 mg/l**

**$Fe^{3+}$ effluent concentration**

**0.029 mg/l**

# CONCLUSIONS

# &

# RECOMMENDATIONS

# Conclusion

## Model

- **First set-up made for iron removal model**
- **Quick insight in alternatives**

## Column experiments

- **After cascade aeration the majority of iron is dissolved $Fe^{2+}$**
- **At Harderbroek oxidation is limited by the pH**

# Conclusion

## Fingerprint

- Operational events have a significant contribution to volume load
- Relation between ppb’s and cleaning frequency

## Recommendations

- Apply a smooth treatment operation
- Recirculation of first filtrate after a backwash event
- Guideline 1 ppb?

# Alternatives Harderbroek

## Replace tower aeration directly after raw water

- More intensive aeration will increase the pH
- No addition of chemicals to the water

## Caustic soda dosage

- Easy to implement
- Relatively sensitive to control

## Crushed limestone filtration

- Automatic equilibrium, no need for control
- More investment costs, 2 filtration steps

# Iron removal at groundwater pumping station Harderbroek

**Karin Teunissen**

**25 May 2007**