CIE4485
Wastewater Treatment

Dr.ir. Arjen van Nieuwenhuijzen
Guestlecture

5. Advanced Wastewater Treatment

TUDelft

Advanced Wastewater Treatment Technologies within the EU Water Framework Directive

Dr.ir. Arjen van Nieuwenhuijzen

Senior Technology Advisor & Co-ordinator
Water, Energy and Materials
Sector Water - Witteveen+Bos

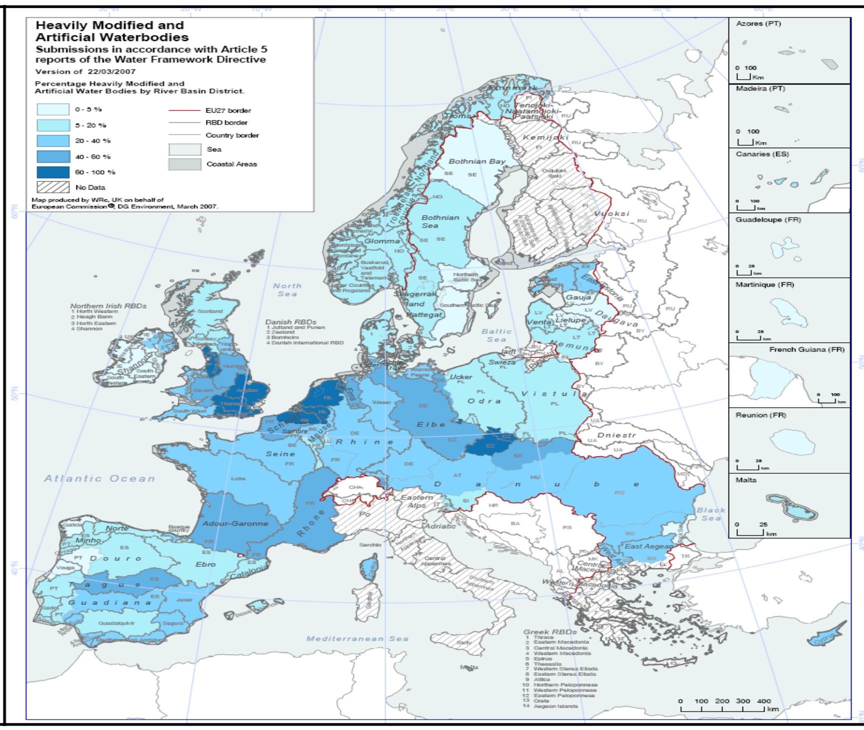
Content: why, what, where and how

- Why to apply advanced physical-chemical (post) treatment
- What kind of technology is required
- Where do we apply these technologies
- How do we apply these techniques

Why, because of WFD

- The European Water Framework Directive (WFD) became effective in 2000
- The WFD aims to achieve and maintain European water bodies in a "good status", chemically as well as ecologically by the year 2015.
- Leading in the WFD goals is the sufficient removal (2015) or zero-emission (by 2021/2027)

Witteveen Bos



Why, because of these substances

Identified actual WWTP-relevant WFD substances:

(1) the nutrients nitrogen and phosphorous;
(2) certain polyaromatic hydrocarbons;
(3) the pesticides hexachlorocyclohexane, atrazine and diuron;
(4) the metal ions cadmium, copper, zinc, lead and nickel;
(5) plasticising additive DEHP (diethylhexylpthalate).

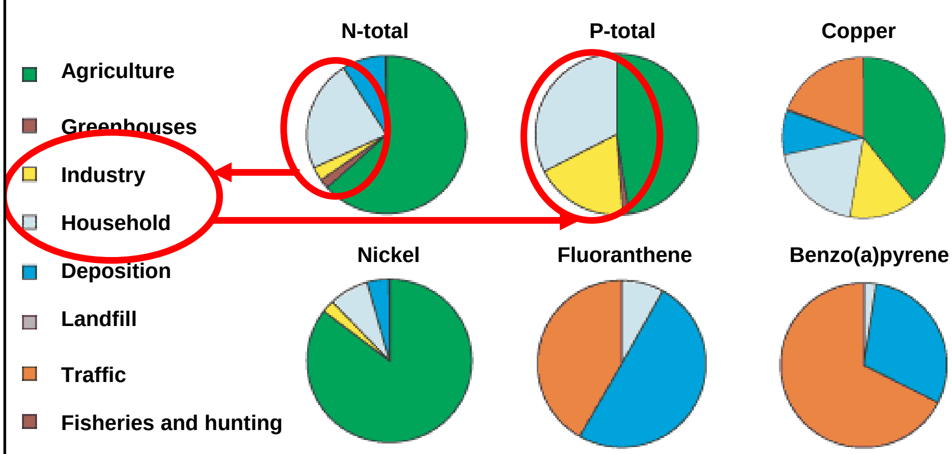
Today: N_{total} < 10 mg/l

Today: P_{total} < 1 mg/l

Future WFD: N_{total} < 2,2 mg/l

Future WFD: P_{total} < 0,15 mg/l

Why, because of these substances



Why, because of these substances

Identified future WWTP-relevant WFD substances:

category	Substances
hormone disrupters	17 α-ethinyloestradiol bisphenol A oestrogen
medicinal substances	ibuprofen anhydro-erythromycine sulphamethoxazol carbamazepine sotalol amidotrizoic acid

Identification of applicable technologies

Witteveen+Bos Consulting Engineers
KIWA Water Research

conducted exploratory research

for

STOWA
Dutch Ministery of Water & Infrasturctur
Urban Water Cycle

Identification of applicabel technologies

The efficiency of treatment techniques for the removal of (priority) substances, which occur typically in extremely low concentrations, is strongly influenced by the characteristics of the effluent as a whole and the presence of other components (the **effluent matrix**).

It is therefore useful to first consider the **relationship** between the **effluent matrix** and the **characteristics of the techniques**.

Identification of applicabel technologies

For the effectiveness of treatment techniques aimed at advanced removal of the identified substances, the following aspects were identified as being important:

- Temperature
- Acidity
- Suspended and colloidal substances
- Organic macro-molecules and degradable organic matter
  e.g. NOM in wastewater influent and effluent (residual N and P)
- Dissolved salts

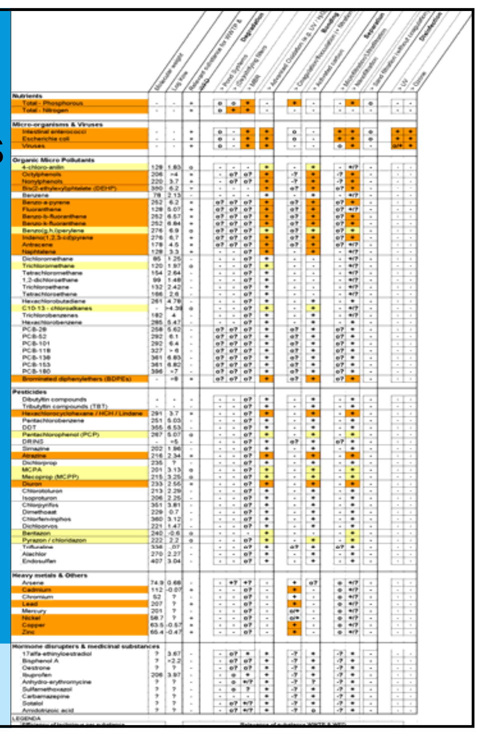
Identification of applicabel technologies

To be identified as an applicable treatment technique, the technique should fulfil the following criteria:

- (potentially) capable of removing the described problematic substances to the levels presented in the required standards;
- applicable at full-scale by 2009;
- capable of treating large flows;
- preferably capable of removing a broad range of substances;
- preferably require little energy, space and additives;
- preferably producing limited amounts of byproducts.

Identified effective treatment techniques per substance

- **degradation**
  - biological degradation
  - chemical oxidation
- **bounding**
  - chemical precipitation techniques
  - adsorption techniques
- **separation**
  - bed filtration
  - membrane filtration
- **disinfection**
  - physical UV light / Ozone
  - chemical desinfection (Cl)



Identified treatment technique 1

PRECIPITATION, COAGULATION / FLOCCULATION

Fact sheet nr. 05

Unit operation		Precipitation, coagulation / flocculation
Treatment principle		Chemical bonding
Applicable for		Advanced effluent treatment
Stage of development		full-scale
Process		
	function:	removal of ions (heavy metals and nutrients) and suspended solids
	feed:	WWTP effluent
Keywords:		precipitation; coagulation; flocculation

Ultra low P-concentration

coagulation aspects:
- Me/P-ratio
- mixing intensity
- mixing time

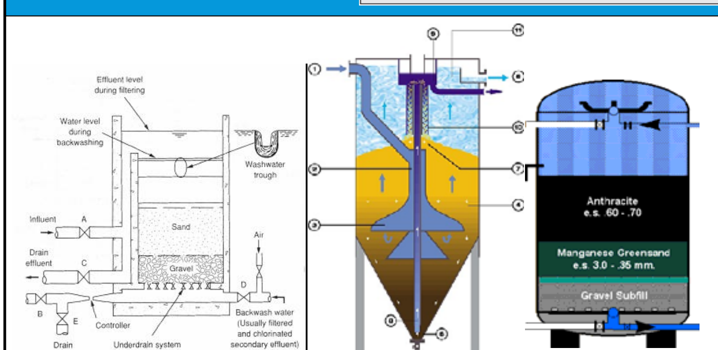
flocculation aspects:
- mixing intensity
- mixing time

Identified treatment technique 2

BED FILTRATION

Fact sheet nr. 08

Unit operation		Separation
Treatment principle		Bed filtration with sand or multimedia
Applicable for		Advanced wastewater treatment
Stage of development		Full-scale
Process	function:	removal of particles, suspended solids, pathogenic organisms, bacteria
	feed:	WWTP effluent
Keywords:		filtration, multi media filtration, sand filtration, fixed-bed, continuous sand filtration, flocculating filtration



Identified treatment technique 3

MEMBRANE BIOREACTOR

Fact sheet nr. 01

Unit operation	Activated sludge system and membrane filtration
Treatment principle	Biological system and separation
Applicable for	Integrated treatment
Stage of development	full-scale
Process	
function:	degradation and conversion of COD, BOD, nitrogen and phosphporus containing substances, removal of suspended solids, pathogenic organisms, bacteria
feed:	WWTP effluent
Keywords:	Activated sludge, membrane filtration

Hybrid MBR Heenvliet

Identified treatment technique 4

ADVANCED OXIDATION PROCESSES O_3/H_2O_2, UV/O_3 and UV/H_2O_2

Fact sheet nr. 03

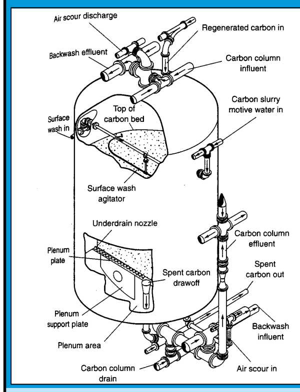
Unit operation	Advanced oxidation
Treatment principle	Oxidation
Applicable for	Advanced effluent treatment
Stage of development	Full-scale development for drinking water production, not yet applied at full-scale for WWTP effluent treatment, techniques researched since 1970
Process	
function:	Disinfection, oxidation of inorganic compounds, organic micro-pollutant oxidation (taste and colour removal, phenolic pollutants, pesticides), organic macro-pollutant oxidation, improvement of biological degradability of water.
feed:	WWTP effluent
Keywords:	advanced oxidation, UV, hydrogen peroxide, ozone

Identified treatment technique 5

ACTIVATED CARBON

Fact sheet nr. 06

Unit operation	Adsorption
Treatment principle	Physical bonding
Applicable for	Advanced effluent treatment
Stage of development	full scale in drinking water treatment; effluent: only pilot scale
Process	
function:	removal of organic micropollutants, pesticides, endocrine disruptors and medicinal substances
feed:	WWTP effluent
Keywords:	adsorption, activated carbon, pesticides, nutrients, medicine residue



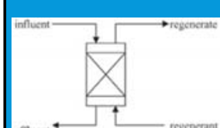
Identified treatment technique 6

ION EXCHANGE

Fact sheet nr. 7

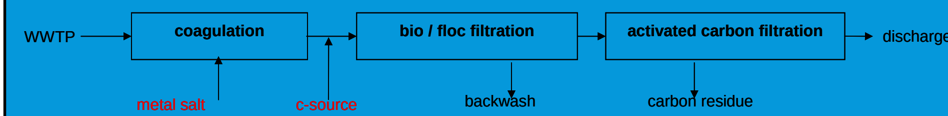
Unit operation	Adsorption
Treatment principle	Bonding
Applicable for	Advanced treatment of WWTP effluent
Stage of development	full scale
Process	
function	removal of dissolved solids and/or organics or heavy metals
feed	pre-treated wwtp effluent

Keywords: advanced treatment WWTP effluent, ion-exchange., selective removal of heavy metals, cadmium, nickel, copper, sink , selective chelating ion exchange resins



Identified treatment concepts

WFD treatment concept 1



How is this applied

- Identified treatment concepts are:
  - based on physical-chemical technology
  - with or without smart biotechnology
  - fast processes -> short retention times
  - chemically and hydraulically design
    - Me/P-ratio’s -> efficient coagulant and flocculant dosage
    - C/N-ratio’s -> efficient carbon dosage
    - mixing (intensity and time)

Treatment costs of WDF technology

WWTP of 20,000 P.E.
= 0.18 - 0.43 EUR/m³ (13 - 31 EUR/P.E./year)

WWTP 100,000 P.E.
= 0.06 - 0.24 EUR/m³ (5 - 18 EUR/P.E./year)

highest costs: coagulation+filtration+advanced oxidation (UV/H2O2)

lowest costs: powdered activated carbon dosage + coagulation + filtration/biofiltration (concept 2 / concept 1)

WFD research on large pilot scale I

- WFD Test Location WWTP Horstermeer (Waterboard of Amsterdam Waternet - The Netherlands)

Conclusions

- WFD requirements are emerging fast (and furious?)

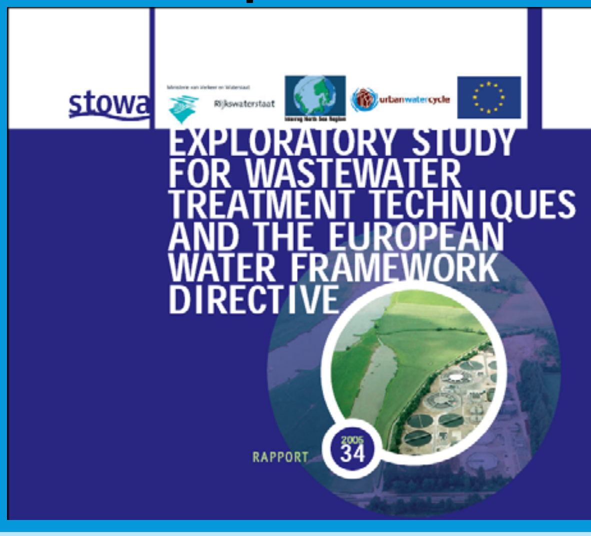
- High potential for physical-chemical technology:
  - advanced coagulation/flocculation
  - filtration
  - biofiltration
  - adsorption

  Preferably in 1 configuration (1-STEP Filtration©)

- Chemically and hydraulically design optimisation
  - Me/P-ratio's - efficient coagulant and flocculant dosage
  - C/N - ratio's - efficient carbon dosage
  - mixing (intensity and time)

- Cost reduction by optimised design

STOWA report WFD Techniques



Digital copy available

Please contact me with business card

or visit:

www.stowa.nl

Goals of the research

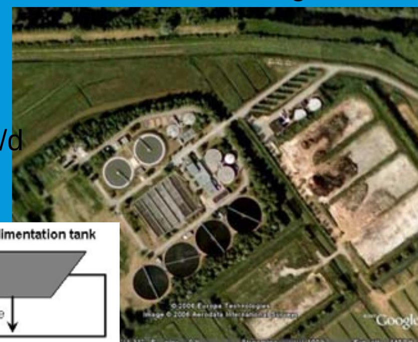
1. Comparing One Step Total Effluent Polishing (1-STEP©) filter (GAC) with Dual Media Filtration (sand + anthracite) for P removal

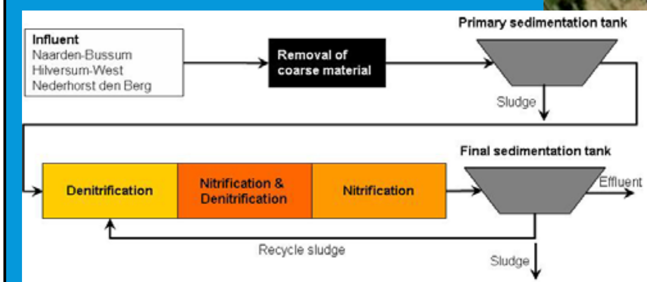
2. Investigate if the target value for Ptotal (<0.15 mg/L) can be reached
   (dry/rainy weather feed and day/night pattern)

3. Investigate the removal mechanism for phosphorus

WWTP Horstermeer

Naarden-Bussum, Hilversum-West and Nederhorst den Berg
Capacity: 200.000 p.e.
Daily Flow: 26.000 m^3
Max. hydraulic load: 5,000 m^3/h
Sludge load: 0,054 kg BOD/kg MLSS/d

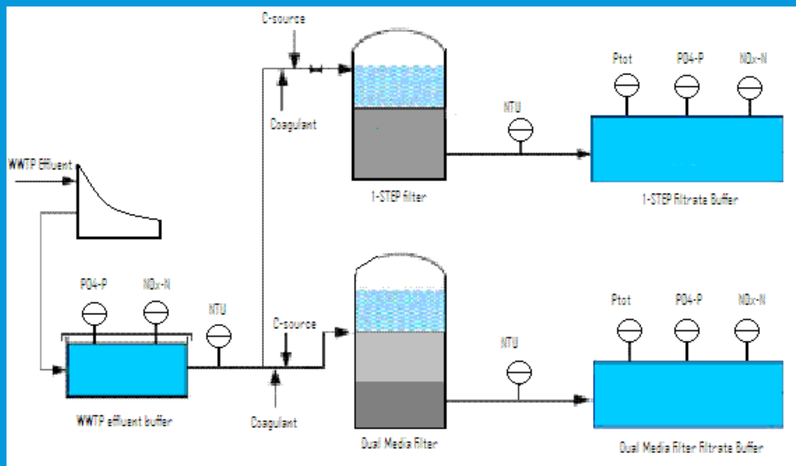




Introduction – Effluent quality

Parameter	Scale	Average	Discharge permit	River Vecht reduction program	Target concentration
COD	mg/L	32			
BOD	mg/L	4			
N-total	mg/L	13.5	14.0	5.0	2.2
Nkj	mg/L	2.9			
NO_3-N	mg/L	10.3			
P-total	mg/L	0.8	1.0	0.5	0.15
P-ortho	mg/L	0.4			
Suspended solids	mg/L	11			

Pilot installations



Process parameters - DMF

- Filtration rate of 10 m/h
- Filter runtime of 12 hours
- MeOH/NO_3-N ratio of 4.7 g/g
- metal/P-ortho ratio of 4.0 mol/mol

- 80 cm anthracite grain size: 2.0 – 4.0 mm
- 40 cm quartz sand grain size: 1.25 – 1.5 mm

Process parameters – 1-STEP©

- Filtration rate of 10 m/h
- Filter runtime of 12 hours
- MeOH/NO_3-N ratio of 4.7 g/g
- PACl dosage
  - PO_4-P < 0,25 MeP 5 mol/mol
  - > 0,25 PO_4-P MeP 4 mol/mol
- 190 cm GAC Grain size: 1.70 – 3.35 mm

Witteveen+Bos

TUDelft Phosphorus Distribution Method

- Developed in co-operation with Witteveen+Bos, Waterboard Rijnland and Water Company Waternet
- Distribution into orthophosphorus, metal bound phosphorus, dissolved “organic” phosphorus and particulate “organic” phosphorus
- Detailed information about coagulation-, flocculation- and filtration processes
- Tool to compare different design and operational settings

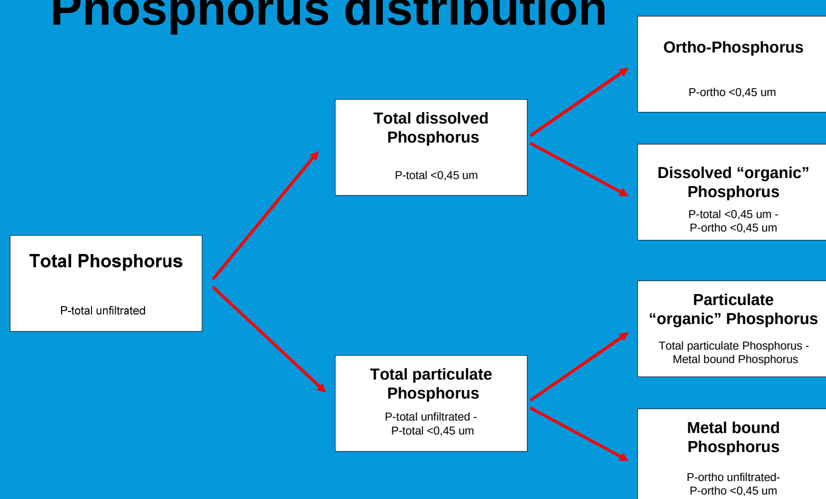
Witteveen+Bos

TUDelft Phosphorus Distribution Method - Measurements

- Orthophosphorus unfiltrated
- Total phosphorus unfiltrated

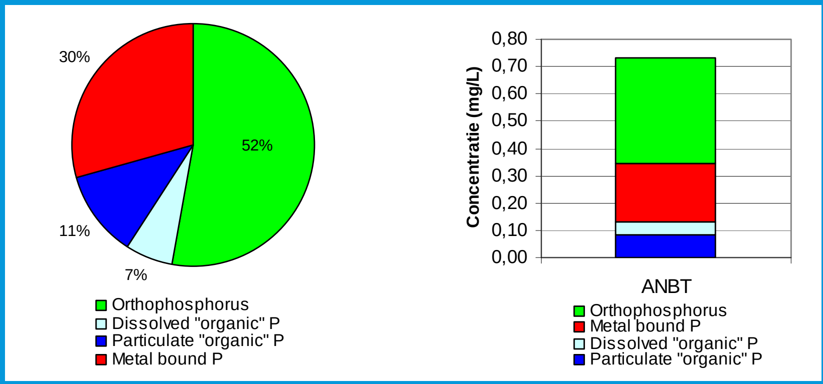
- Orthophosphorus < 0,45 µm
- Total phosphorus < 0,45 µm

Phosphorus distribution



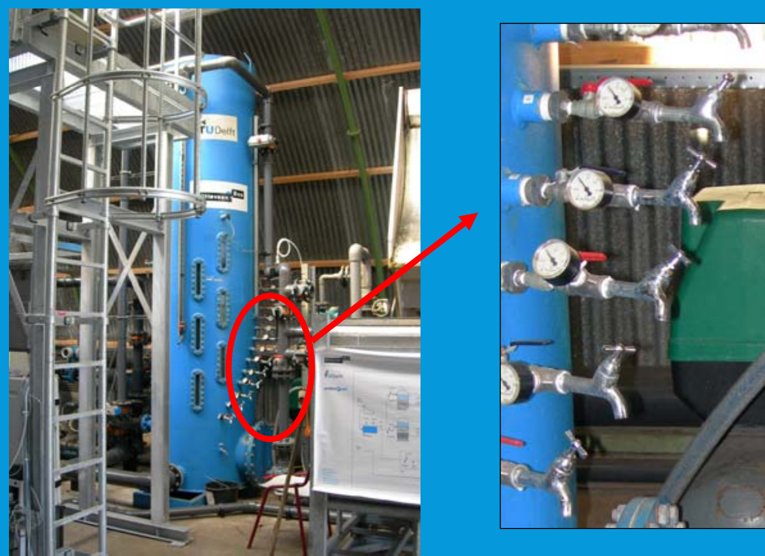
P distribution WWTP Effluent (57 samples)

	Orthophosphorus	Dissolved "organic" P	Particulate "organic" P	Metal bound P
ANBT	0,38	0,05	0,08	0,22



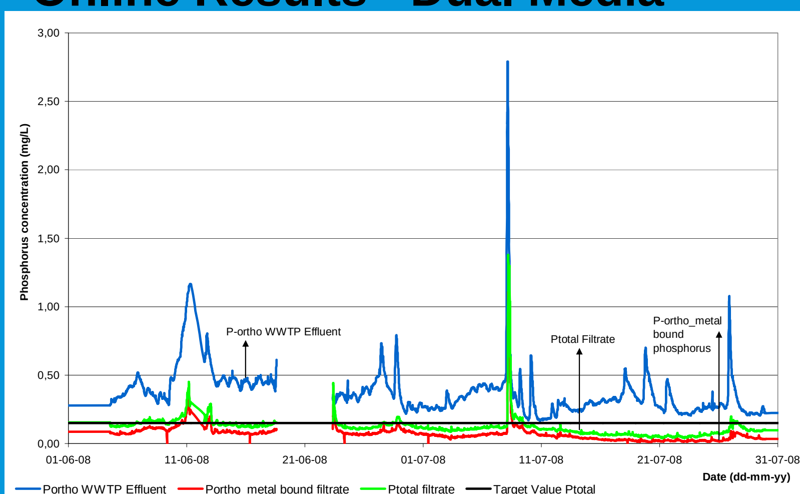
Profile Measurements

- To investigate the removal through a filter bed
- Samples: WWTP effluent, the upper water layer, every 10 or 20 cm in the filter bed (by taps which are placed on the side of the filter) and in the filtrate
- Orthophosphorus (< 0.45 µm), nitrate, nitrite, COD are measured. Additionally the oxygen concentration.



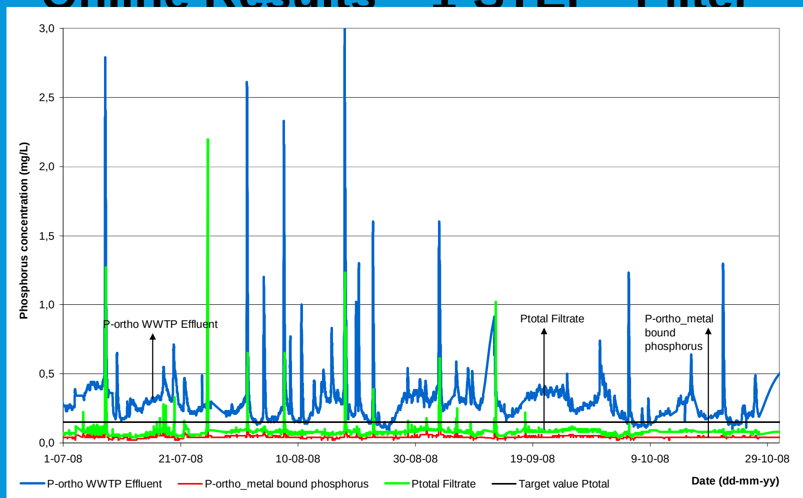
Witteveen+Bos

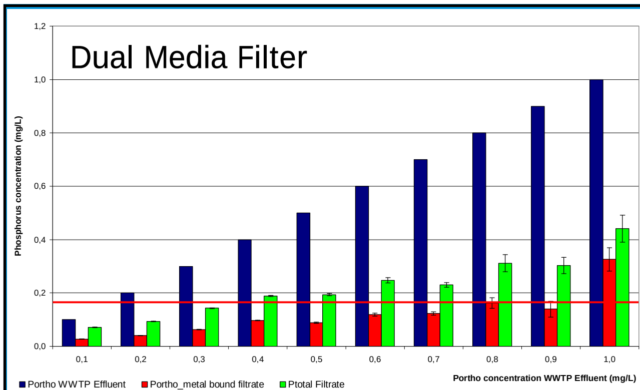
Online Results - Dual Media

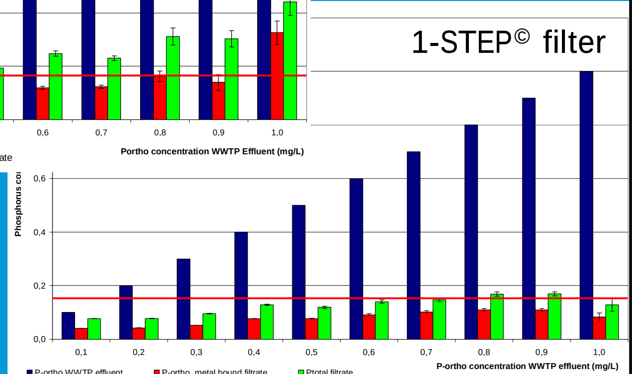


Witteveen+Bos

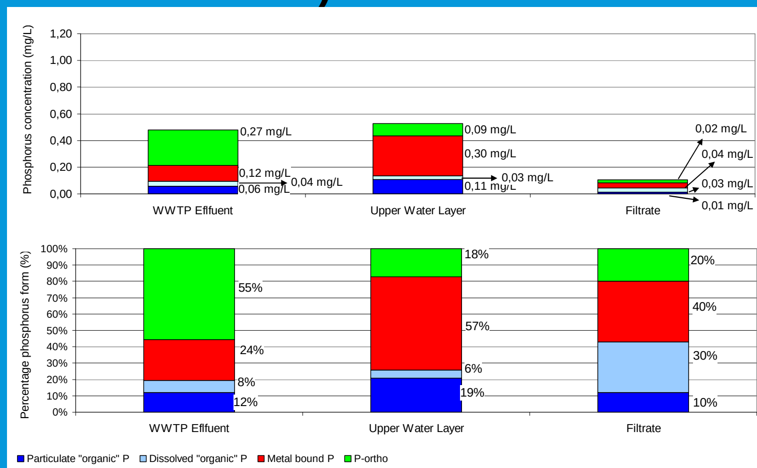
Online Results – 1-STEP© Filter



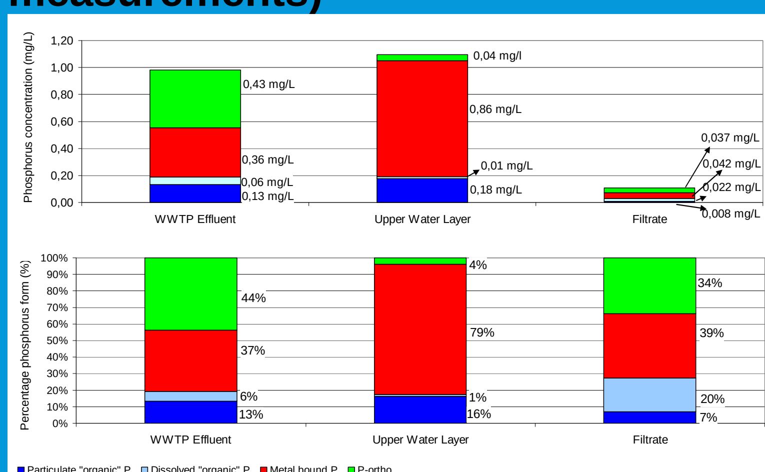




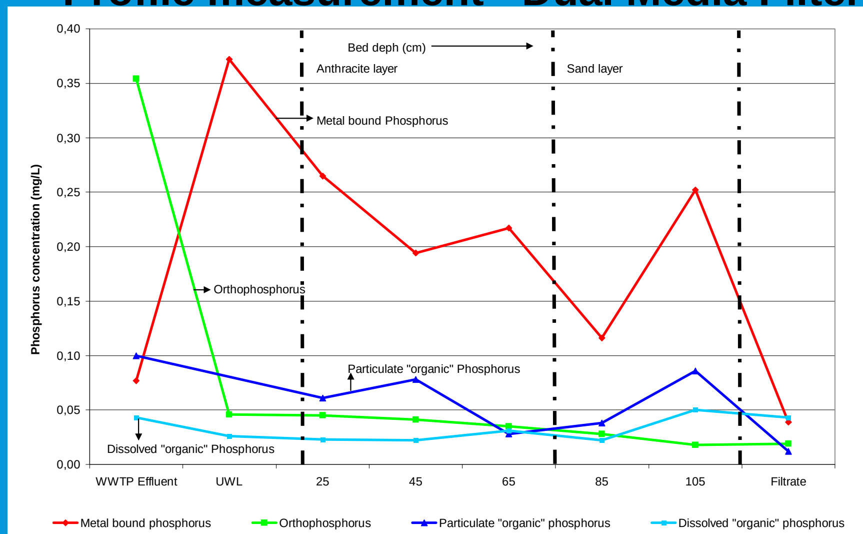
Phosphorus distribution (14 measurements)



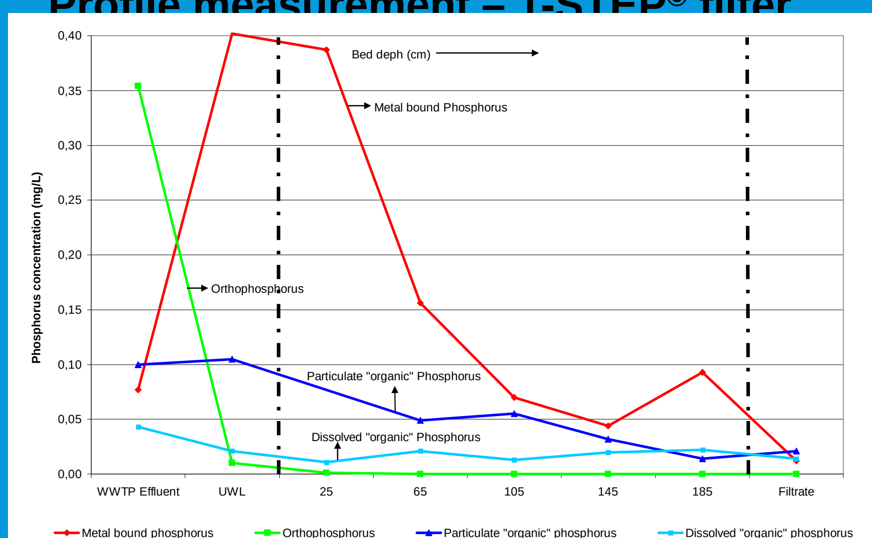
Phosphorus distribution (14 measurements)



Profile measurement - Dual Media Filter



Profile measurement – 1-STEP© filter



Conclusions

- The Dual Media Filter and the 1-STEP© filter can fulfil the target value of 0.15 mg Ptotal/L
  - The Dual Media Filter for 0.3 mg Portho/L in WWTP Effluent
  - The 1-STEP© filter for 0.7 mg Portho/L in the WWTP Effluent
- The removal mechanism for phosphorus is filtration
- P distribution and profile measurements have proven to be a useful tool to compare different filter concepts

Overview

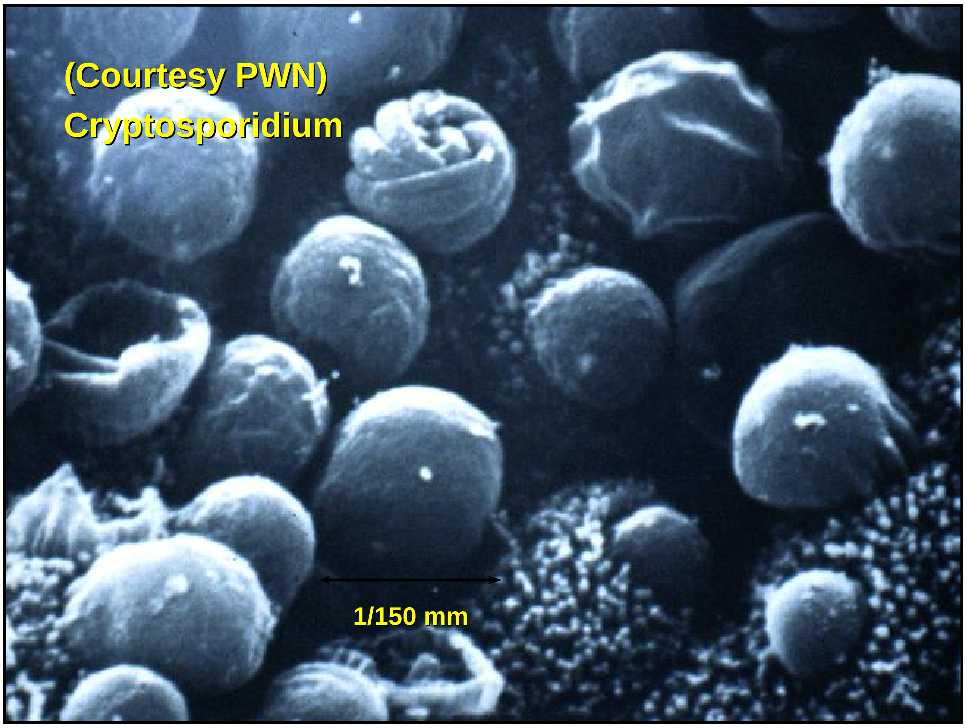
- Study, (pilot) research, design & engineering
- Conventional & advanced
- Special interest:
  - desalination incl. pretreatment
  - polishing relative to (micro) organics
  - wastewater re-use
- Brief introduction to portfolio of signature projects

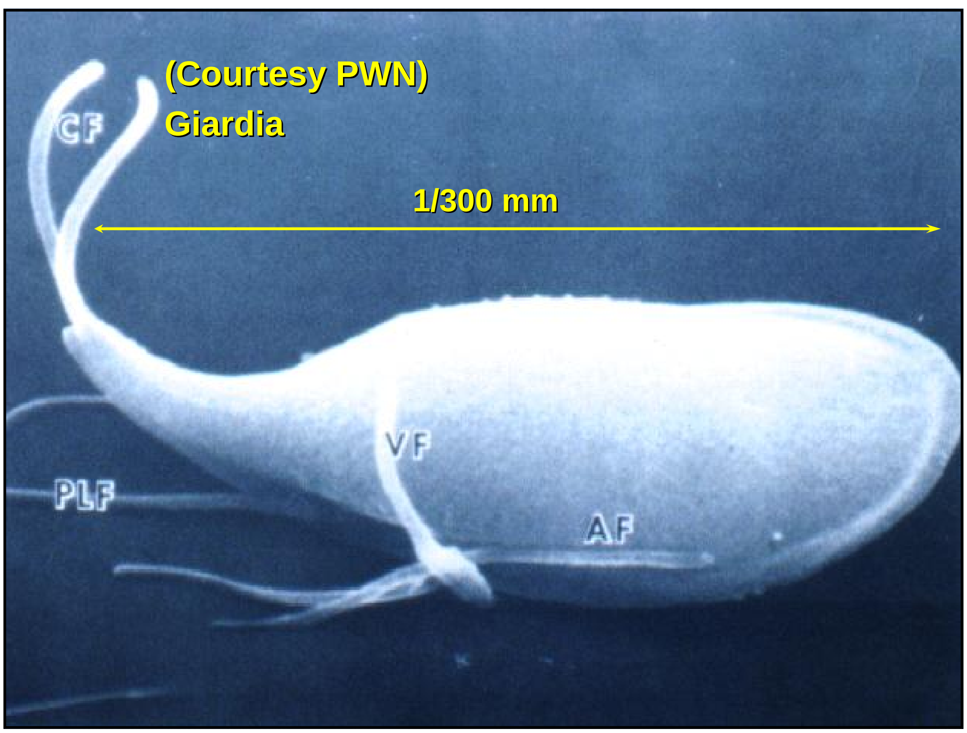
UV/H2O2

- UV disinfection & UV/H2O2 AOP
  - Andijk 100 MLD conventional/UV/H2O2/GAC + Heemskerk 150 MLD UV/H2O2/GAC + Beerenplaat 450 MLD conventional/UV/GAC

UV and its applications

- Recent breakthrough for primary disinfection
  - Traditional disinfection (chlorine, ozone) inadequate for certain pathogens
  - Traditional disinfection involves by-products (tri-halomethanes and bromate)
  - UV involves excessive dosage for killing Giardia and Crypto, but ……
  - 90-ies research has revealed low dosage exposure ***Inactivation***
  - UV is now a very popular crypto barrier

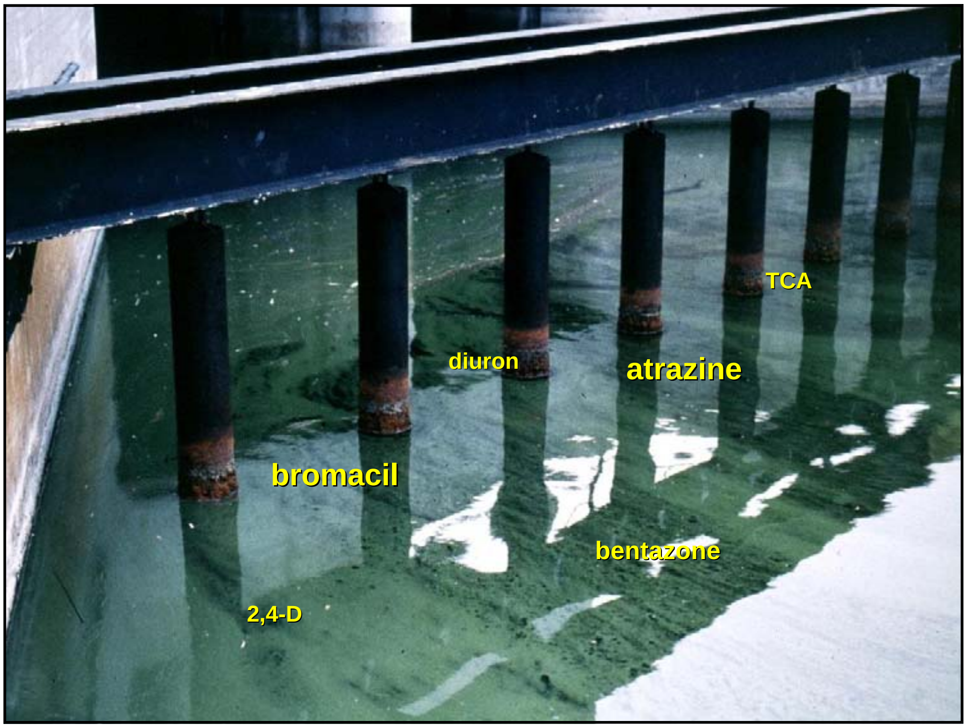

(Courtesy PWN)
Cryptosporidium
1/150 mm

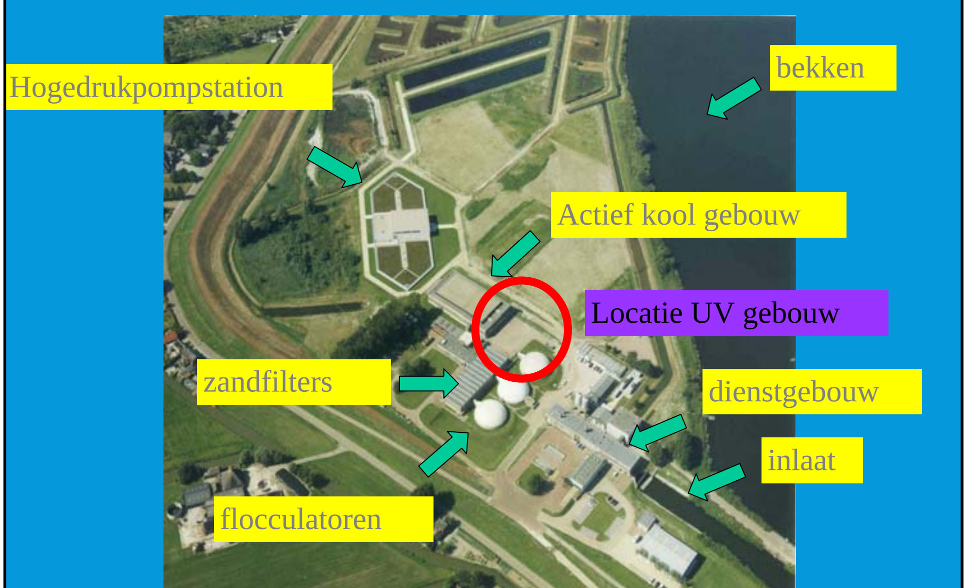

(Courtesy PWN)
Giardia
CF
1/300 mm
VF
PLF
AF

UV and its applications

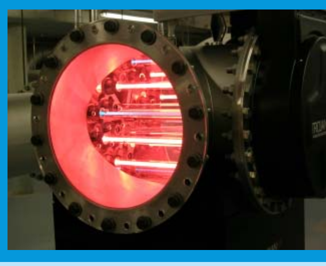
- UV is recognised as potential technology for advanced oxidation
- UV in combination with H2O2 proves to be a successful duo:
  - certain organics susceptible to UV photolysis
  - certain organics susceptible to hydrogen radicals (OH*)

- Effective for pesticides, medicine and hormone residuals and other trace organics





Witteveen Bos

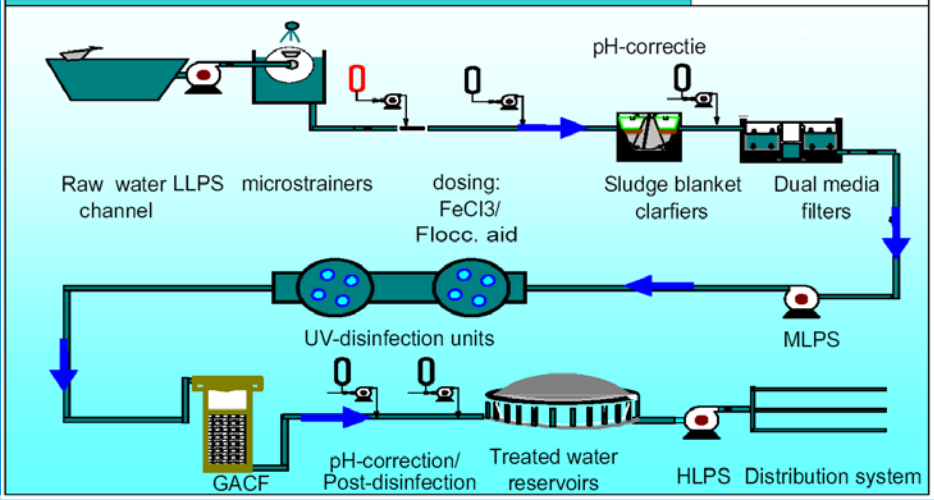


Witteveen Bos

Berenplaat WTW, Rotterdam

Witteveen Bos

Berenplaat process with UV-disinfection



Dutch water technology @ work.

Heemskerk-2 (UV/H_2O_2-GAC)

Thank you for your attention