Advanced phosphorous and particle removal

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IWAMA Webinar 4

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Importance of phosphorus

12. frequent element of the crust of earth

- Phosphorus is a chemical element. Symbol **P**
  ordinal number 15 and has a specific weight of 31 g/mol
- Greek φως-φορος „light carrying “, given by the shining of the white phosphorus in the reaction with oxygen.
- P was discovered in 1669 by Hennig Brand, a German pharmacist and alchemist.

- Phosphorus is essential important for all organism.
  - P-compounds are parts of DNA- and RNA-molecules
  - The phosphorus containing compounds ADP/ATP are playing and important parts in the energy metabolism of all cells.
- A man with 70 kg contains about 700 g phosphorus, from which 600 g is bound in the bones
- Important nutrient for the growth of plants and essential fertilizer
- Main resources: Morocco, South Africa, Russia, China and USA
  Resource remain **only about 300 years**

Eutrophication

Effects of nutrient discharge

Nutrient (mainly N, P) emission

Increased algae growth („Algae bloom“)

Dead algae settle to the ground

Degradation of algae with oxygen consumption

Oxygen depression/no O_2 available anymore

Mineralization and setting free of nutrients

Interactive Water Management

Example of eutrophication in the Baltic Sea

Objectives of P-removal

- Prevention of the eutrophication of water bodies especially in:
  - Lakes, dammed or tide influenced water bodies, Northern Sea of Baltic Sea
- Factor of minimum for the growth of plants: **N : P = 7:1**.
- Classification of lakes:
  - **Eutrophic**; nutrient rich lakes, in depth about 0-30%, O_2-saturation, only 2 m sight in depth, high production of algae, **tot. P~ 45 - 85 µg/l**
- River according the German Surface water ordinance
  - 50 µg P/l large rivers in the middle mountain; inlets to the Baltic Sea
  - 50/100 µg P/l all other rivers
- Limiting value of WWTP in Germany according wastewater ordinance
  - 10,000 - < 100,000 PE: 2.0 mg P/l
  - > 100,000 PE: 1.0 mg P/l
  - Special regional restrictions (e.g. Helcom agreement)!

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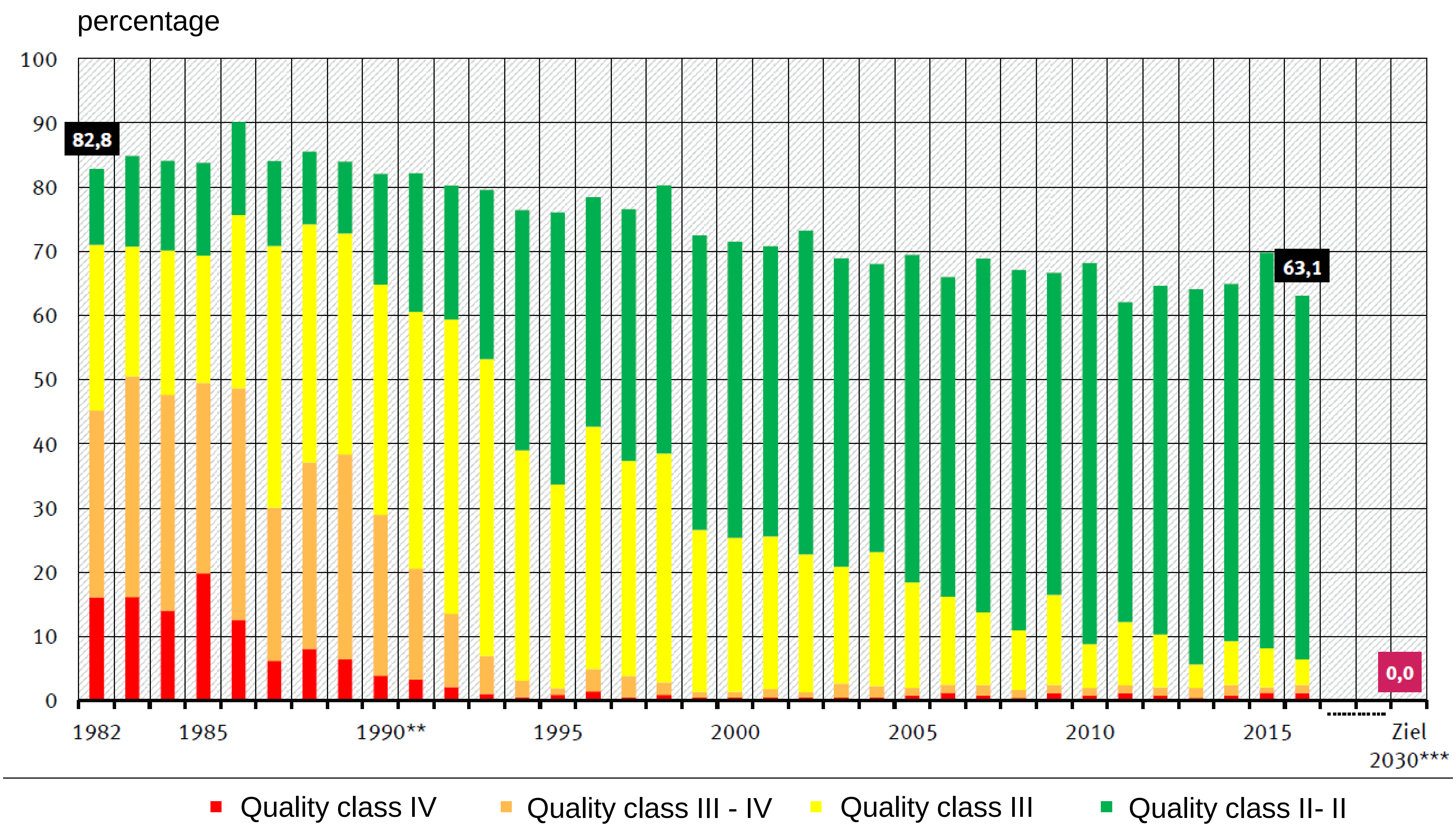
Situation in Germany

Measurement points, which exceed the orientating value of total Phosphor



Objective: **Quality class II**

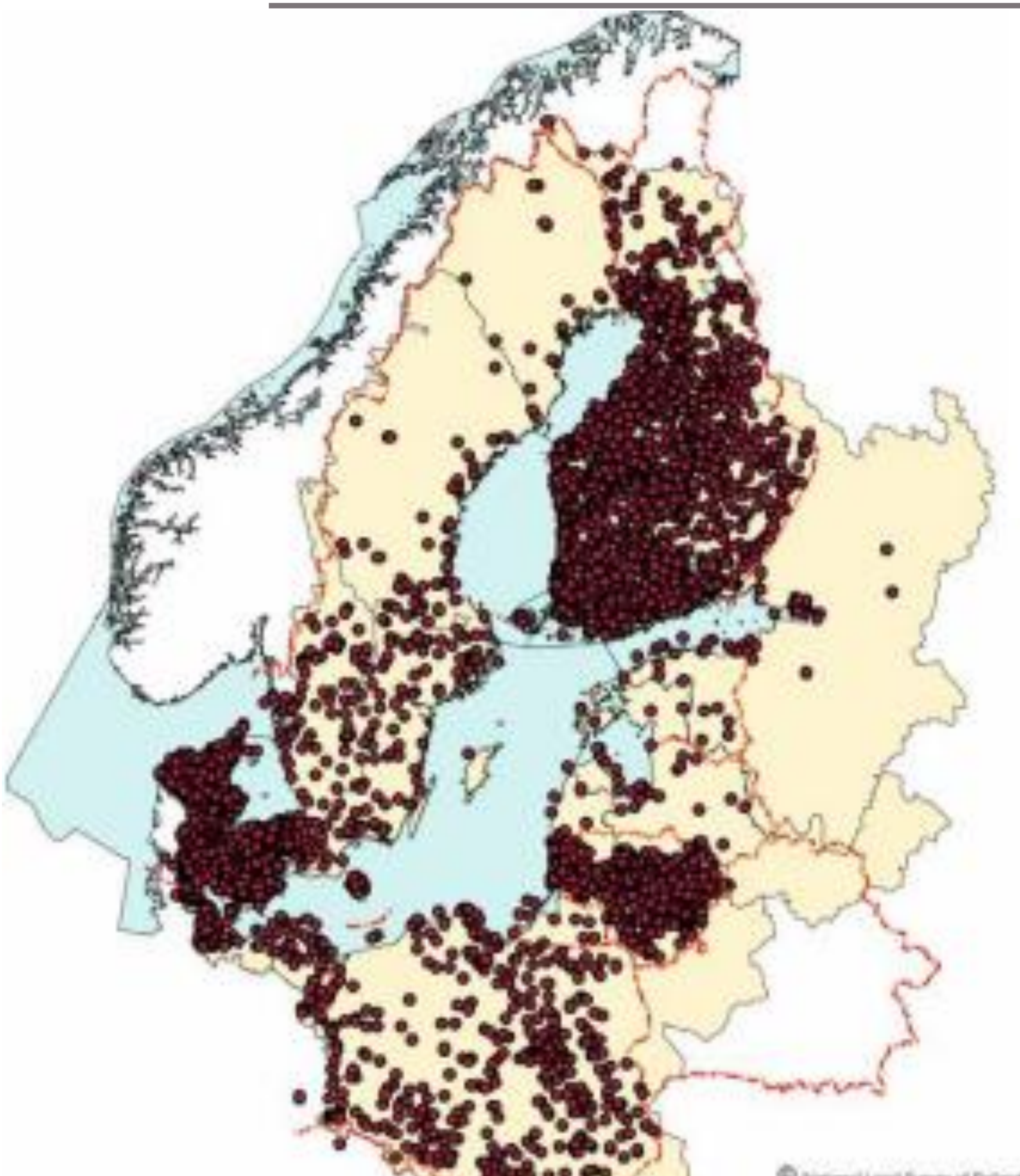
Some facts of the Baltic Sea

Baltic Sea facts

- A shallow (Ø depth: 53 m) and almost landlocked sea
- One of the largest bodies of brackish water in the world
  - Salinity 2 -20 ‰
- Unique and fragile ecosystems with naturally low numbers of species
- Highly sensitive to all kinds of pollution
- Surrounded by many large cities and regions with intensive agriculture and industry
  - 85,6 mio. people; Neighbouring countries: 9
  - Catchment: 1,7 mio. km²
- Some of the busiest shipping lanes in the world

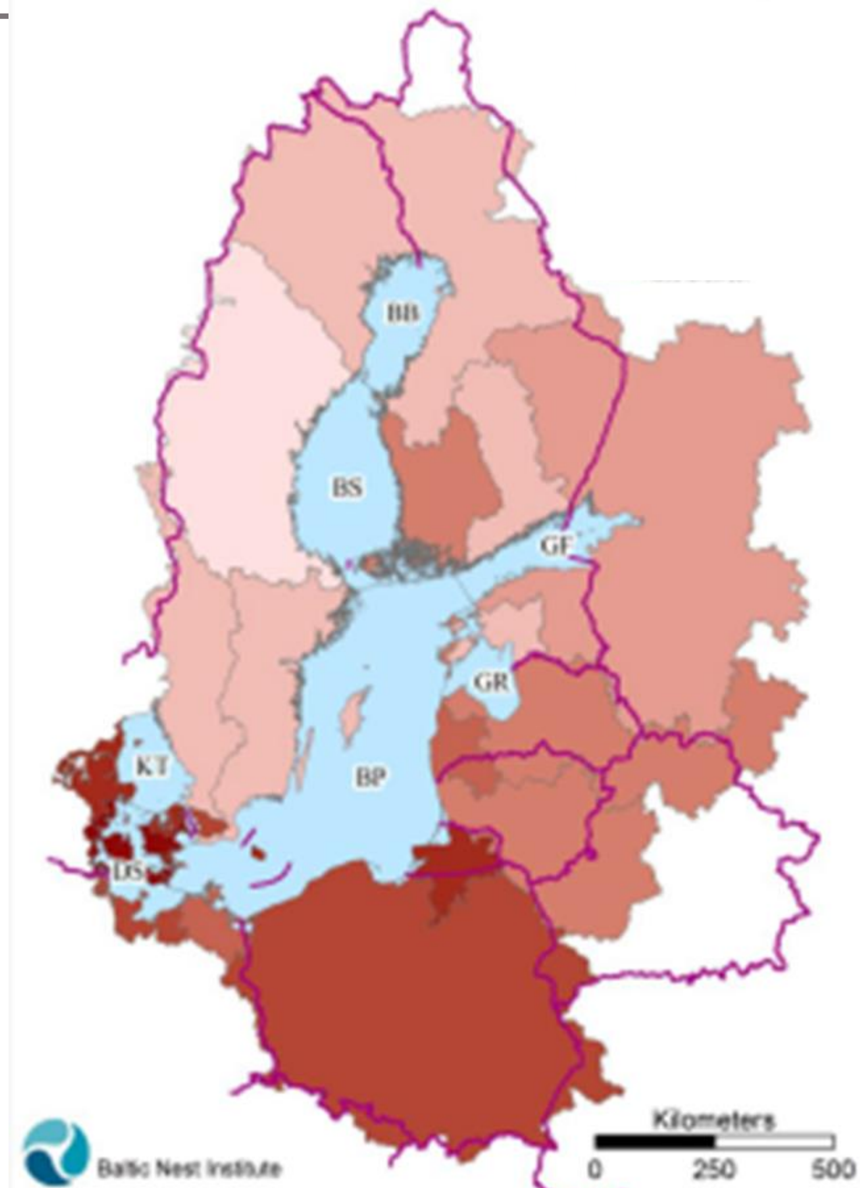
Source: Helcom

Treatment plant >10,000 PE (Left); Land cover, catchment area and sub-basins (right) of the Baltic Sea



P-Emission into the baltic sea (2006)

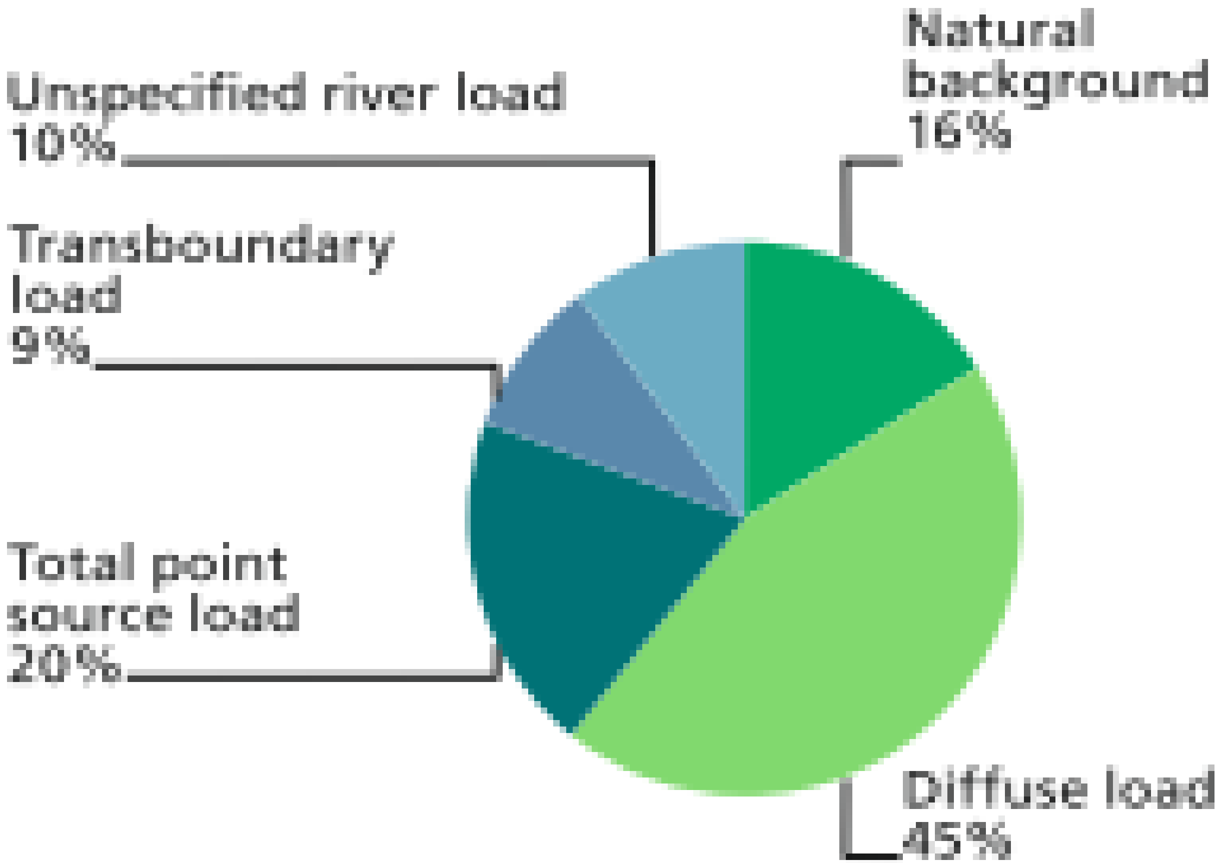
Area-specific riverine phosphorus inputs (kg/km²·a)



Aera specific P load [ka P/(km

Source: Helcom

Proportion of different sources (in %) contributing to the phosphorus inputs into the Baltic Sea in 2006.



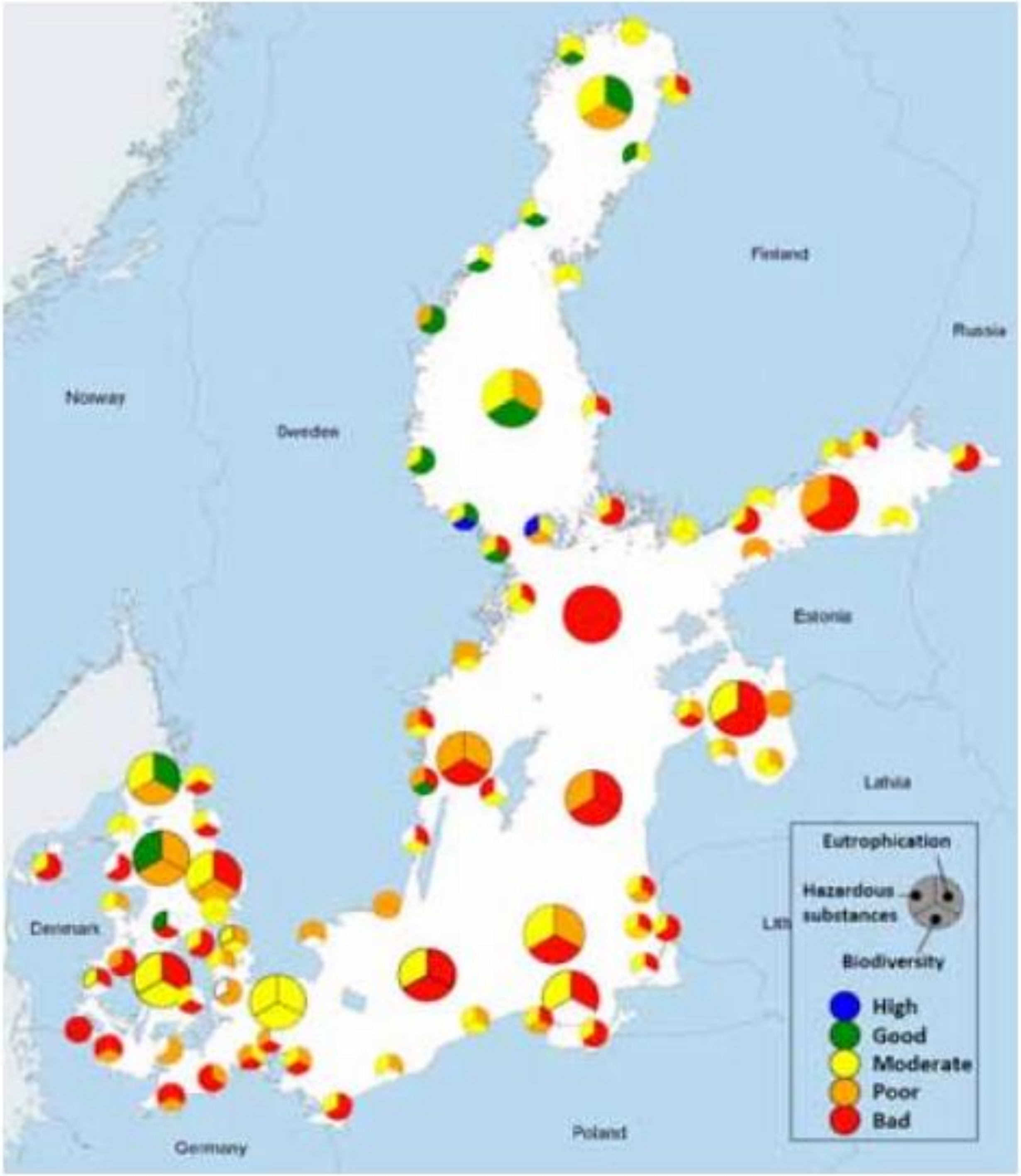
a) Total waterborne phosphorus 28,370 t

Source: Helcom


Taivallahti Bay, Helsinki, July 2013


Rügen, July 2013

Status of the Baltic Sea



Origin and estimation of the specific P-load in municipal sewage [in g P / (E·d)]

Origin of phosphorus	1975	2015
Metabolism products	1.6	1.6
Washing powder for textiles	2.25	0
Household detergents/washing-up liquid	0.75	0.24
Other P-sources	0.4	0.05
Sum, related to PE	**5.0**	**1.8**
Industry/trade/settlements (as PE)	1.2	1.2
Average Concentration in Germany (mg/l)	14	5.6

Only ortho-phosphate (PO_4^-) (68% of the inlet) can be removed from the water by precipitation and following particle separation!

Upcoming fraction of organic solved and none solved phosphorus

phosphonate, hardly degradable organic P-compounds from textile industry and from heat-/power-production

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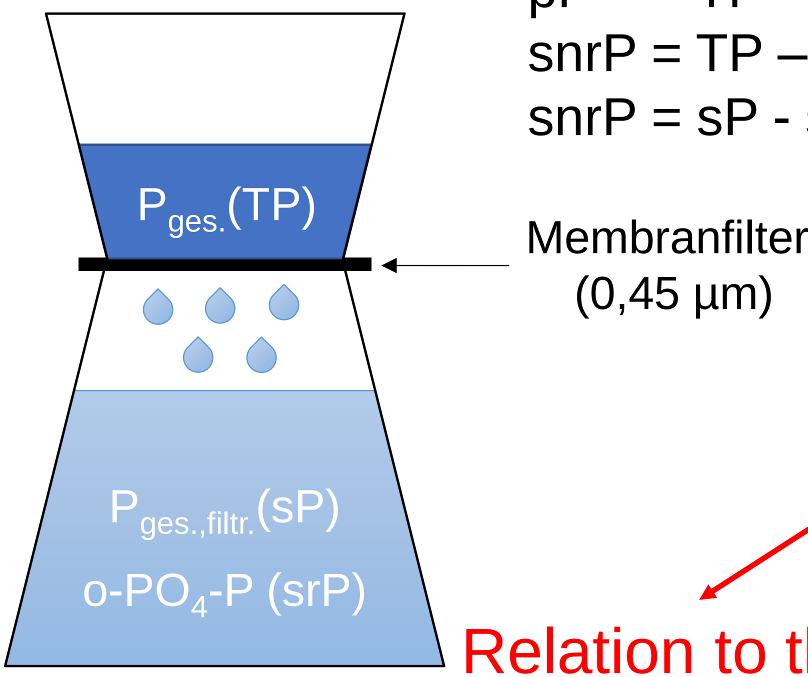
Fractions of Phosphours in the sewage

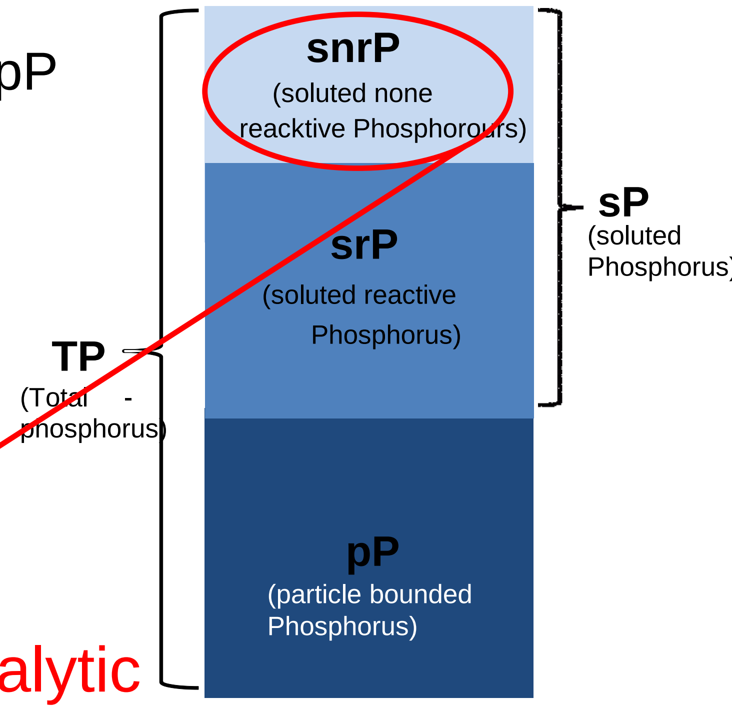
Calculation snrP

pP = TP – sP

snrP = TP – srP – pP

snrP = sP - srP

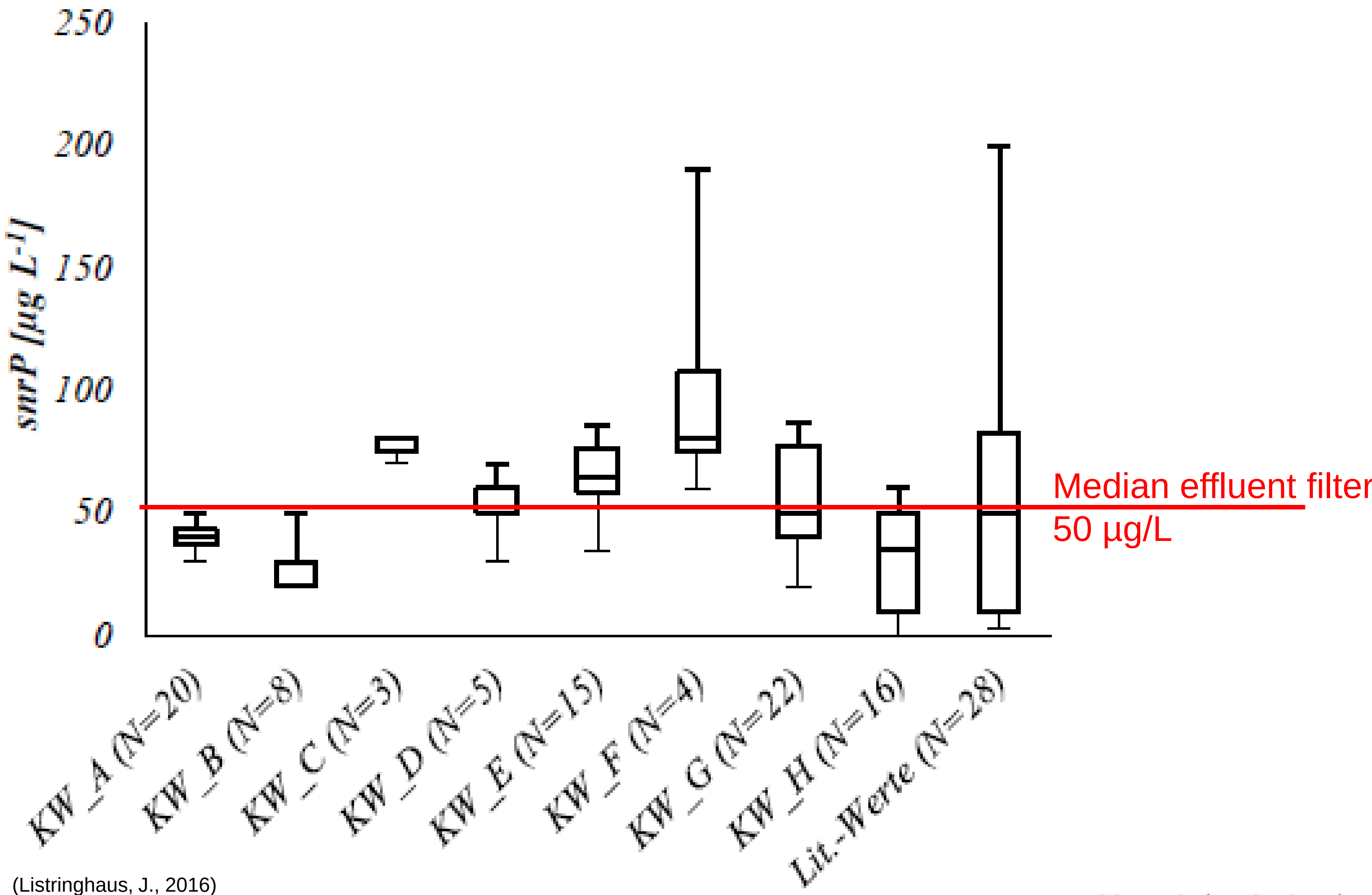




Relation to the analytic

→ P-compounds not reactive with flocculants

snrP effluent values of biofilter
Comparison to litrature



(Listringhaus, J., 2016)

Chemical and biological aspects

Chemical phosphorus removal

Coagulant and reactions

Applying metal salts:

$$\underbrace{Me}_{\text{Fe; Al}}^{3+} + PO_4^{3-} \Rightarrow MePO_4$$

Reaction with the coagulant (example iron chloride ($FeCl_3$)):

$$FeCl_3 \cdot 6\ H_2O + PO_4^{3-} \Rightarrow \mathbf{FePO_4} + 3\ Cl^- + 6\ H_2O$$

Unavoidable by-reaction (Building of (Hydroxide flocs):

$$FeCl_3 \cdot 6\ H_2O + 3\ H_2O \Rightarrow \mathbf{Fe(OH)_3} + 3\ H^+ + 3\ Cl^- + 6\ H_2O$$

- Building of hydroxides requires always an overdosage of coagulant → β value
- And an additional sludge production

Applying calcium (2 different precipitation products):

$5Ca_2^+ + 3PO_4^{3-} + OH^-$	$\Rightarrow Ca_5(PO_4)_3OH$	(Hydroxylapatit)
$Ca^2 + CO_3^{2-}$	$\Rightarrow CaCO_3$	(Calciumcarbonate)

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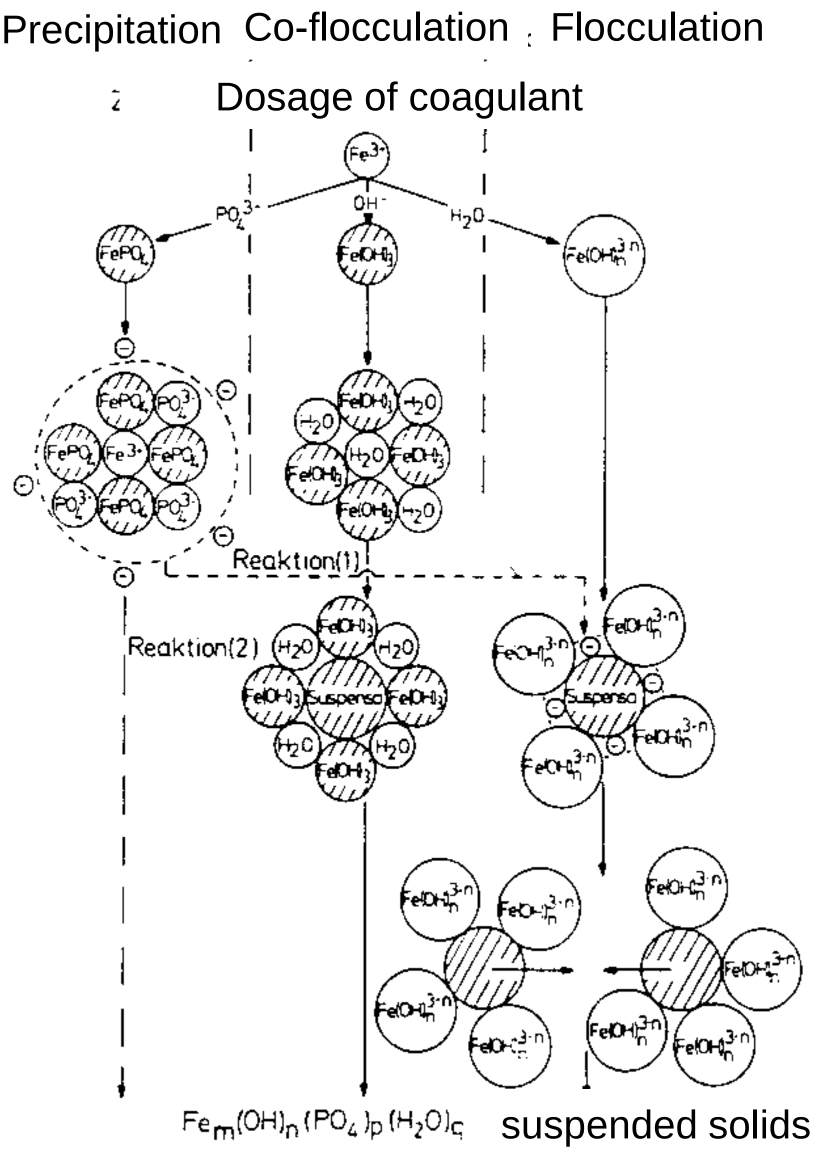
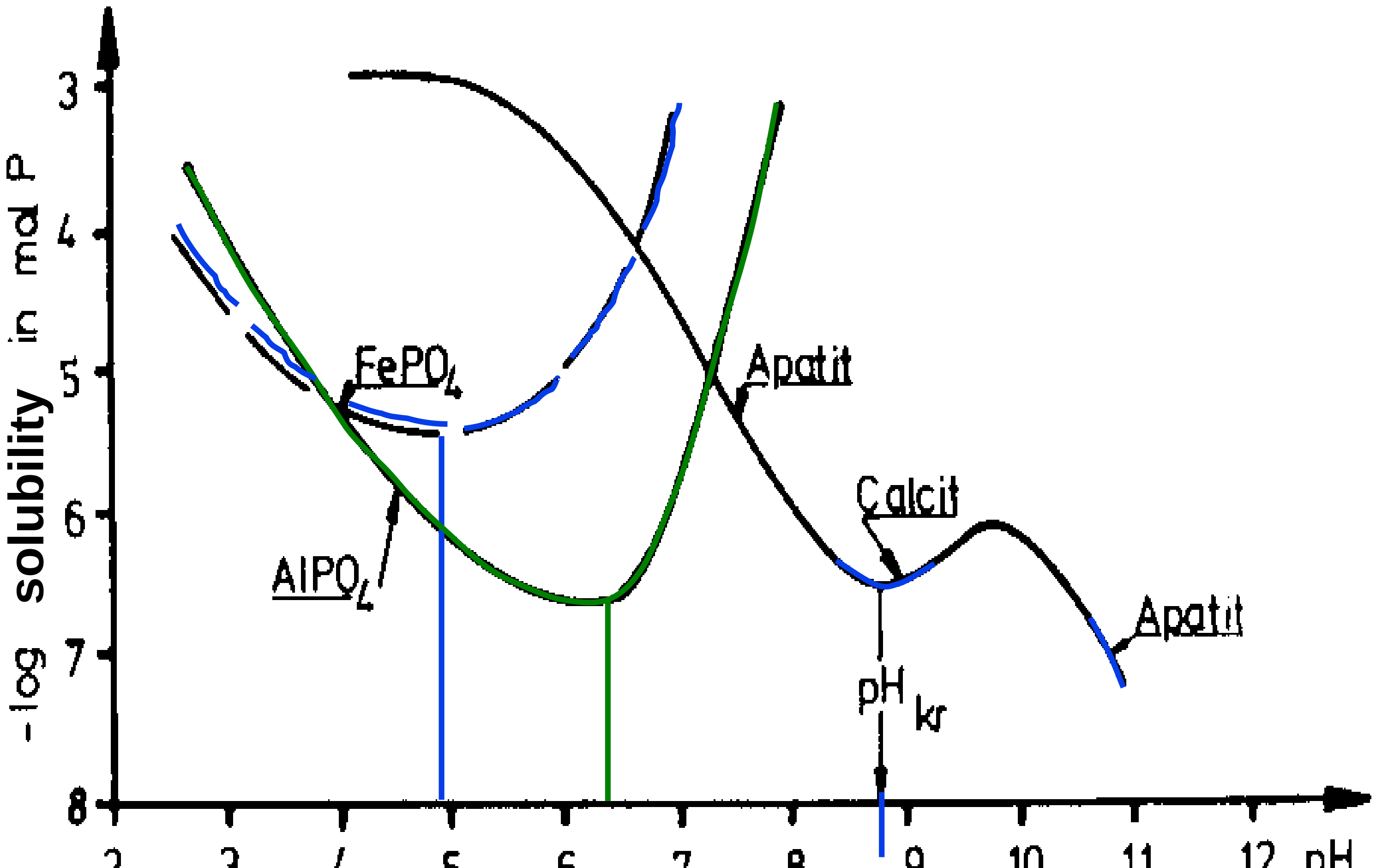
Flocculation process



Equilibrium Phosphate and Fe, Al, Ca-Concentrations



Calculation of the amount of the precipitant

ß-value: **relative amount of precipitant with the unit [mol Me/mol $X_{P,Prec}$]**

$$\beta_{prec} = \frac{X_{Me} / AM_{Me}}{X_{P,Fäll} / AM_{P}} \qquad [mol\ Me / mol\ P]$$

β = 1,0 stochiometric dosage

β = 1,5 50 % over stochiometric dosage

with:

X_{Me} **necessary amount of precipitant (metal) (mg Me/l sewage),**

$X_{P,Fäll}$ **phosphorus to be precipitated (mg P/l sewage),**

$$X_{P,prec} = C_{P,In} - C_{P,out} - X_{P,BM} - X_{P,DN} - X_{P,BioP}$$

AM_{Me} **atomic mass of metal (mg/mmol),**

AM_{P} **atomic mass of phosphors (mg/mmol)**

and the atomic mass AM: (P) Phosphor: 31; (Fe) iron 56 ; (Al) aluminium 27

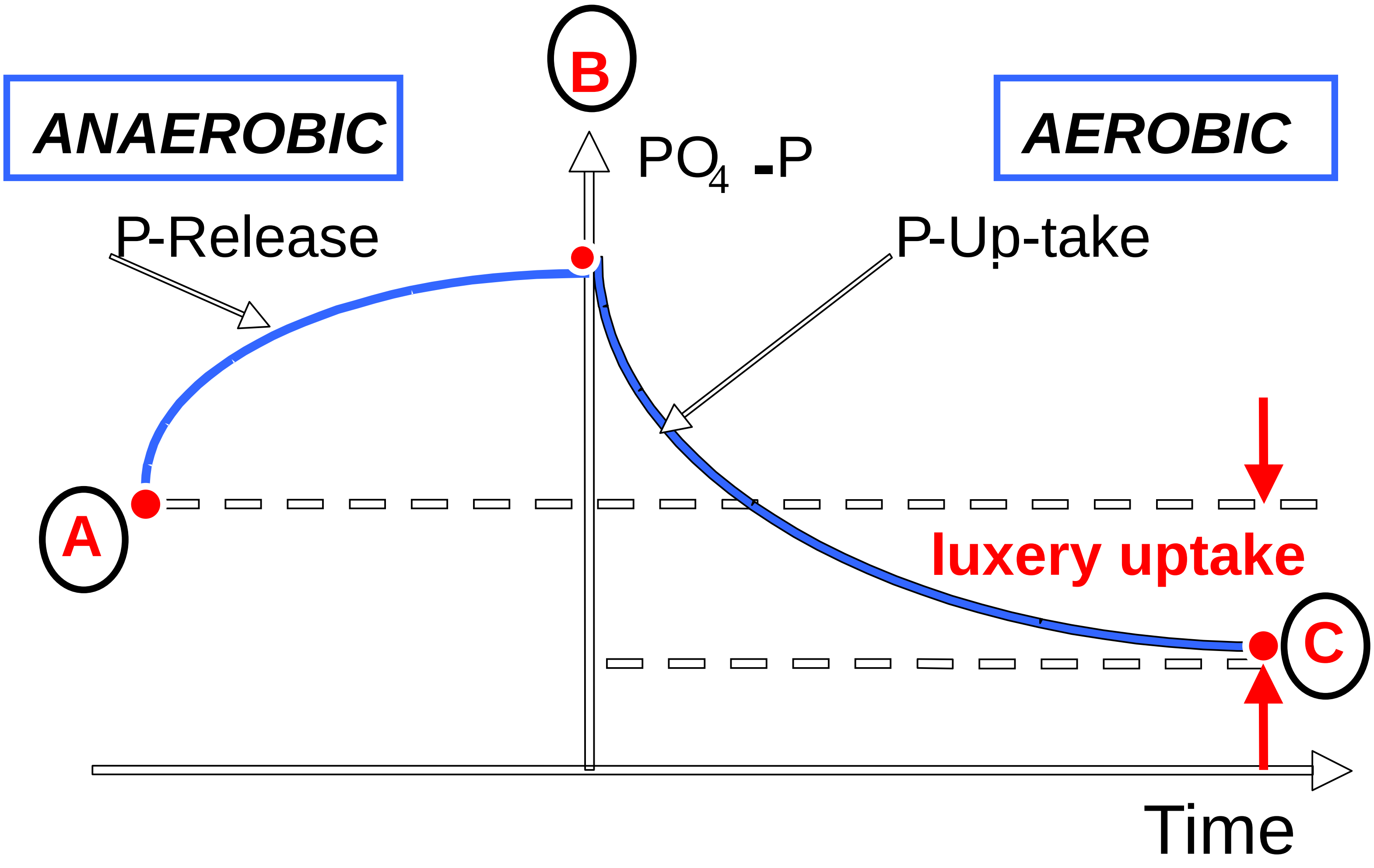
According the kind of bounded P in the sludge:

X_{PBM} = 1,0 % (nitrification, COD Elimination)

X_{PBDN} = 0,5 % (denitrification)

X_{PBioP} = 1,0 % (anaerobic tank)

Principle of the enhanced biological P-elimination



Biological P-Elimination

Advantages:

- No additional agents (flocculants) necessary
- Decrease of salts in the effluent of a WWTP
- Lower additional sludge production
- No additional heavy metals in the sludge
- No disturbances possible for the nitrification process

Disadvantages

- Higher investment cost for the construction of the anaerobic tank
- Sometimes instable process, so often additional chemical dosage is required
- In winter time higher tendency of bulking sludge
- High content of volatile fatty acids (> 100 mg/l)
- Sufficient O_2-input into the activated tank to realize a high P-uptake

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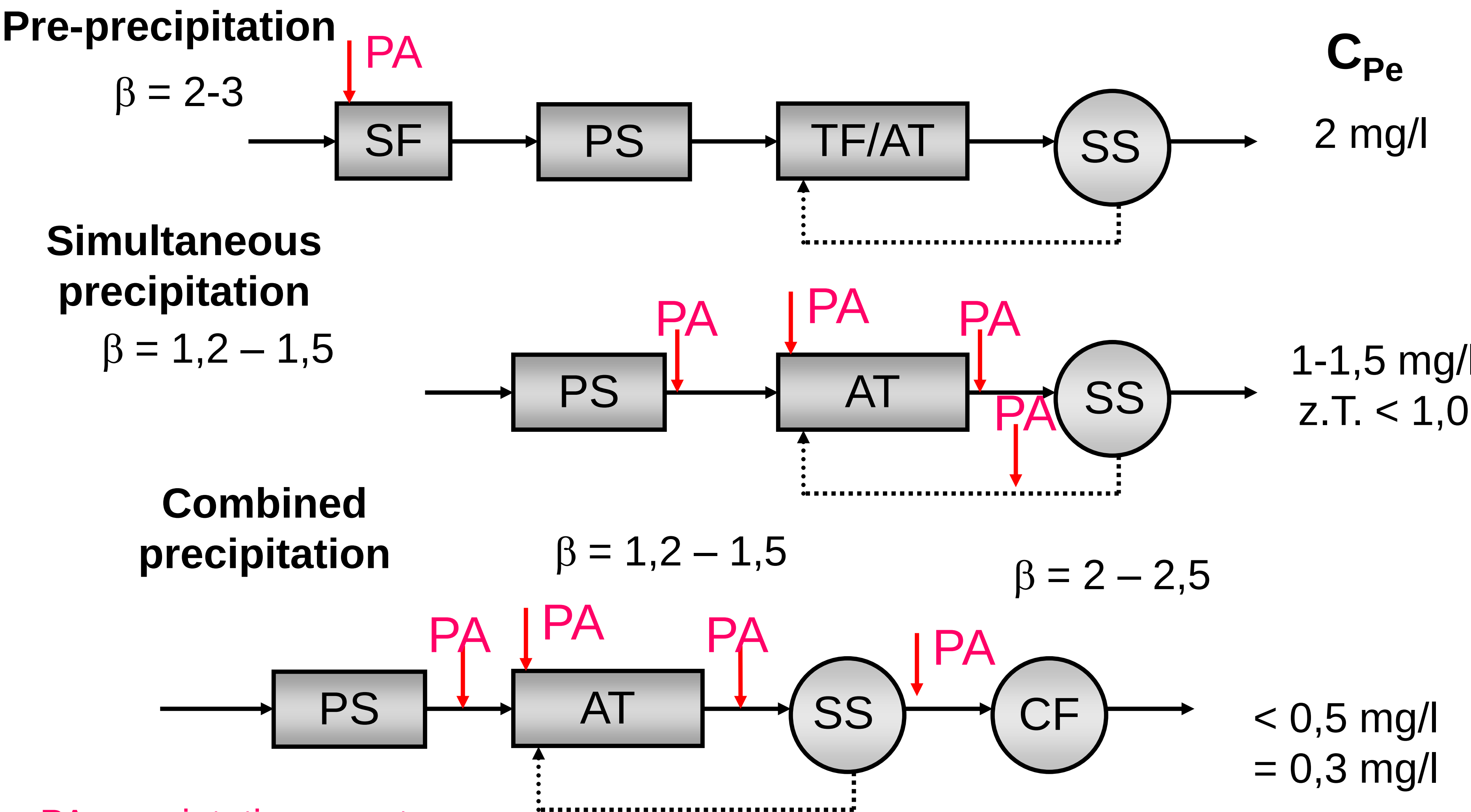
Process technology of phosphorous removal

- Chemical, biological -

Processes of the chemical P-elimination



PA: preciptation agent

Dosage of the precipitation agent

- at locations with by flow increase turbulence
- in short distance of the storage tank
- hydraulic direct jump
    - ➡ Increase of the cross section,
    - ➡ absorption chamber of weirs,
    - ➡ Drop construction
    - ➡ junction of part flows
- Installation of mixer with a high frequency
- Installation of screens and static mixers
- Archimedes screw (e.g. filtration)
- Pressure side turbulence of pumps
- Aerated flow section

Protection pipe

(Fe^{2+})

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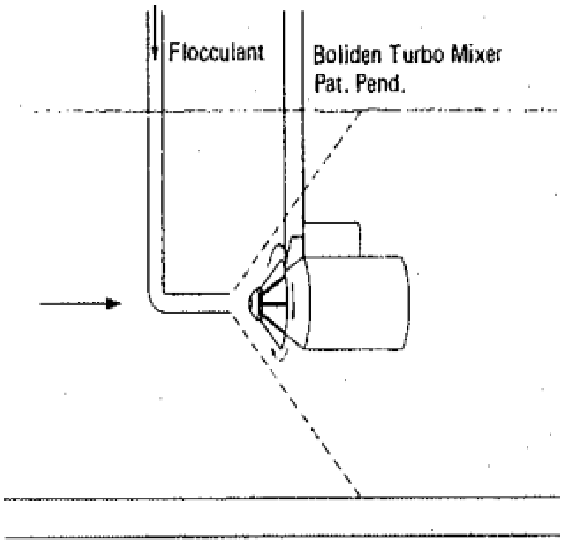
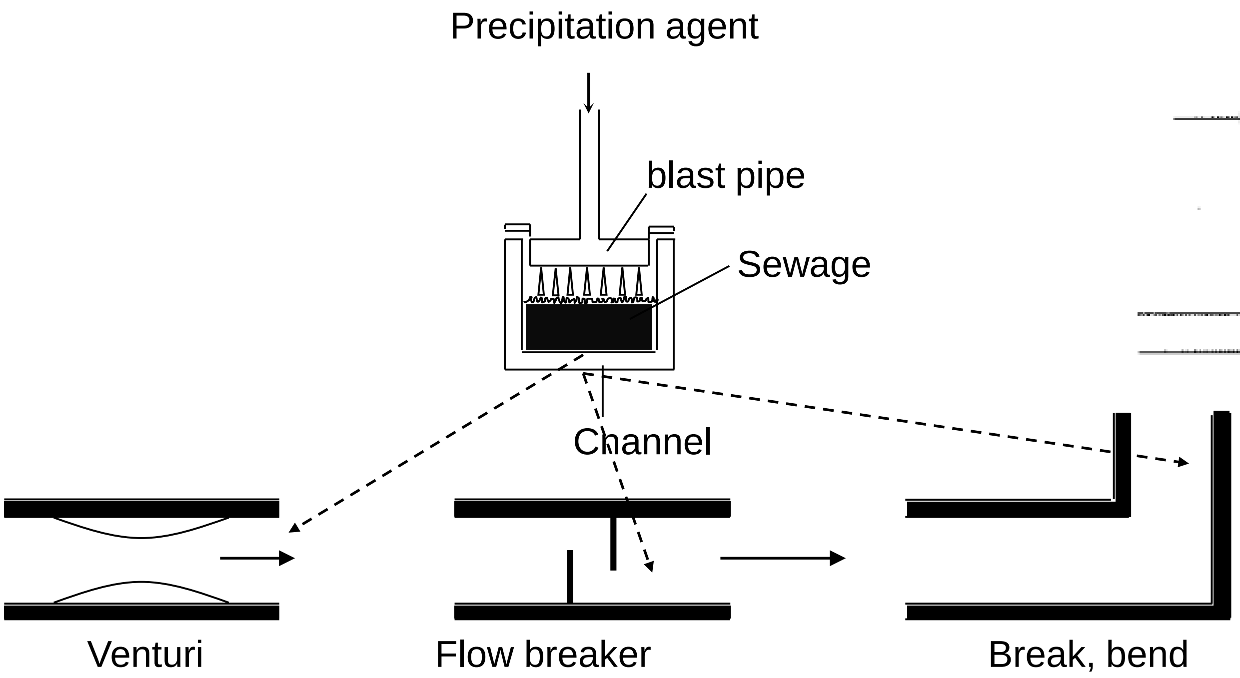
Example of good location for the dosage of precipitations agents





Examples of location for dosage

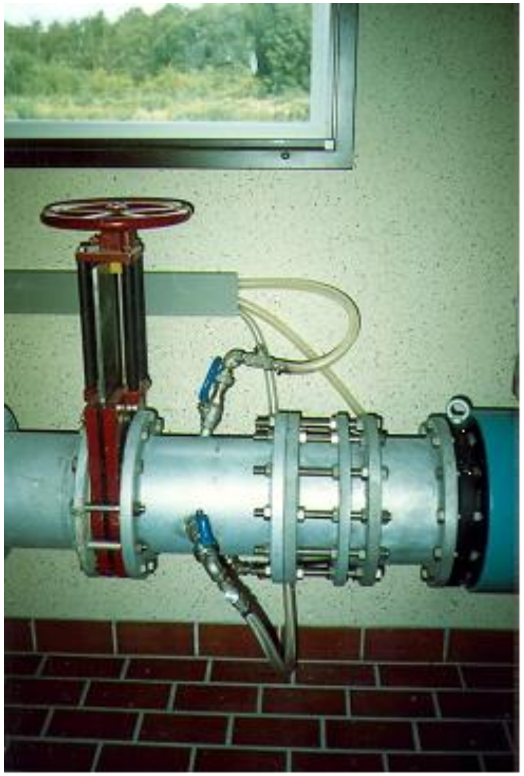
Bad solution

- bad mixing of the flocculant
- durch Randlage kaum B nearly no contact to the complete water surface

good solution

- Dosage into the change of flow direction
- but better would be over the whole cross-section

Examples of location for dosage



Good mixing conditions

- special injections form different side of the pipe
- Against the flow direction

- also good mixing conditions
- but danger of corrosion

Storage of the flocculation agent

- Sealed filling place
- Separated catchment of losses of the flocculation agent

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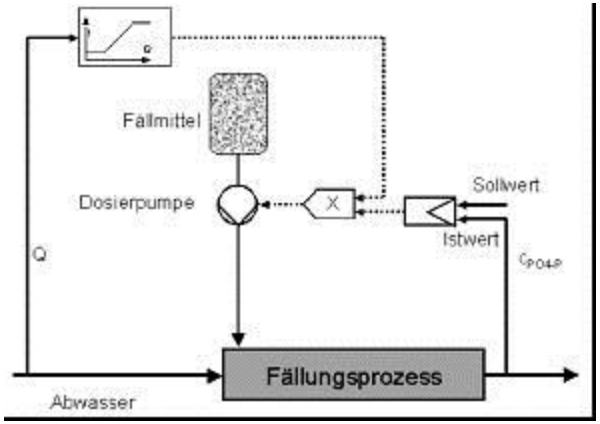
Control concepts

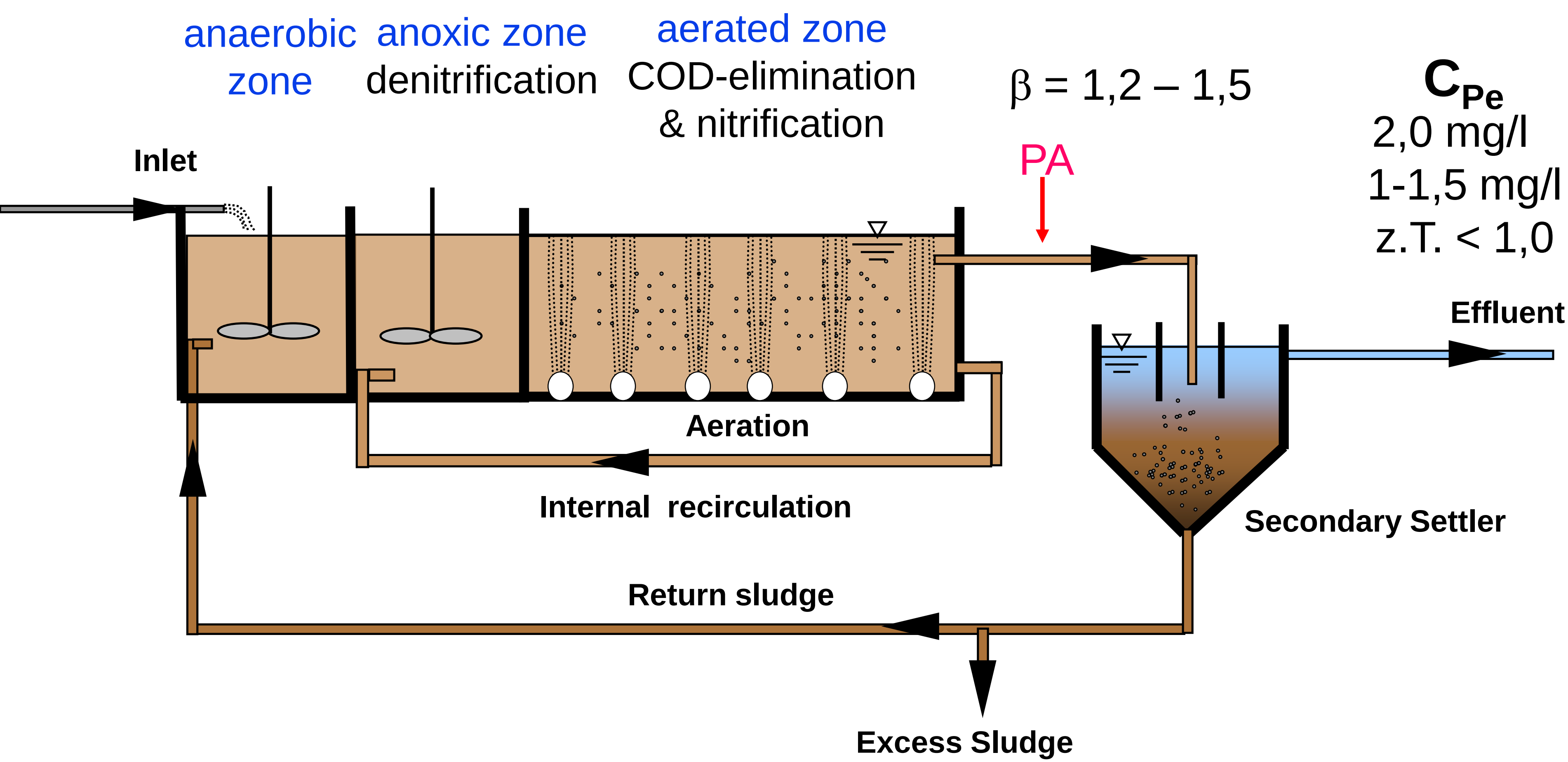
Process	**Size of WWTP**	**Amount of flocculation agent**
Control according pre-seted time	Not recommendable (only small WWTP)	--
Control according a flow graph	Small WWTP	-
Control in relation to the flow	Mid sized WTTP	+/-
Control according to the load in the inlet	Large WWTP	++
Control of $C_{PO4\text{-}P,Effluent}$	Large WWTP	++



TMLNU, 2009, changed

Enhanced biological-P-removal (Bio-P)

Phoredox-process (Detention time: 0,5 to 0,75 h)



Example

WWTP Lübeck-Priwall

Advanced Phosphorous removal technologies

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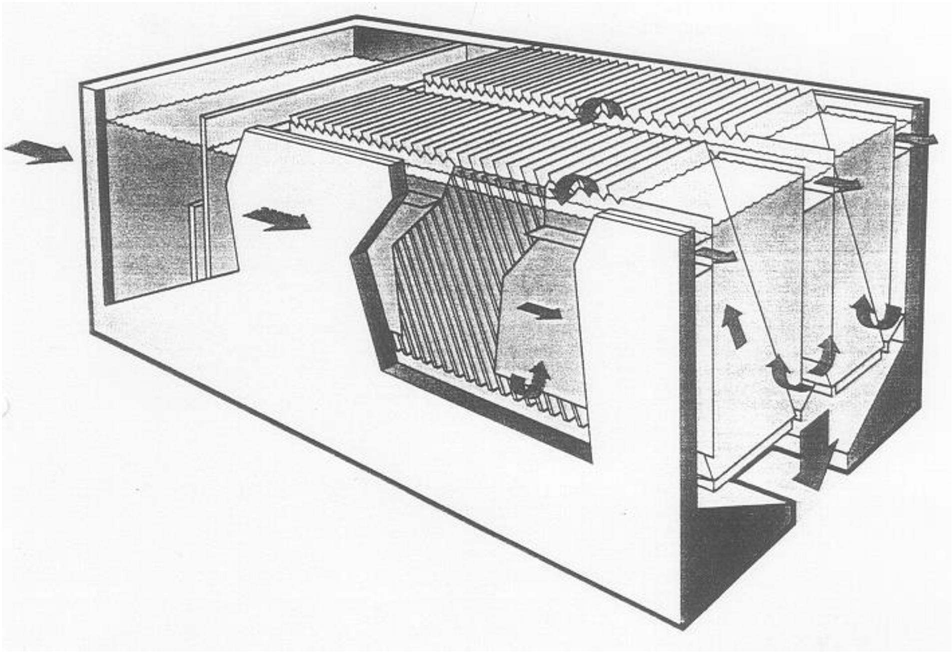
Processes for advanced P-removal

- First step:
  Residual precipitation and flocculation of Phosphorous
  - Dosage of agent and flocculation tank is required
- Post precipitation and separation of the flocs with:
  - Settling tank, Lamella separator, flotation
  - Micro-sieve
  - Cloth filter
  - **Coagulation filtration**
    - Down flow deep bed filter
      - Discontinuously back washed
      - Continuously
- Membrane-filtration (post positioned)
- Biomembrane-reactor

Operational results of lamella separator Post-precipitation (5 plants)



lamella	AFS_o[1)] [mg/L]	AFS_e [mg/L]	η [%]	$gesP_o$ [mg/L]	$gesP_e$ [mg/L]	η [%]	CSB_o [mg/L]	CSB_e [mg/L]	η [%]
Average	9,5	3,0	73	4,46	0,62	86	38	36	29
Minimum	13,0	0,3	-	2,14	0,21	75	34	24	29
Maximum	6,6	6	-	5,81	1,44	92	42	90	30

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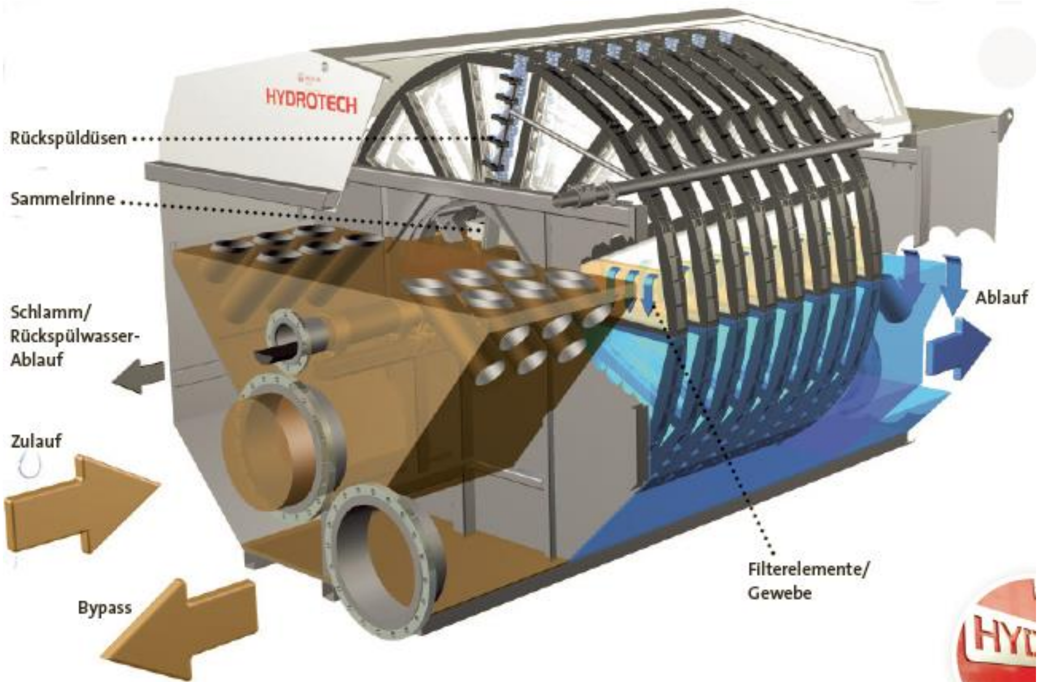
Modern Micro-sieve (Hydrotech)

- closed meshed, monofile texture (width 10 – 100 μm)
- System is only damed to 2/3 of the diameter
- Filter velocity $v_{F,TW} \approx$ 10,0 m/h - 20,0 m/h
- Smaller particles than mash width removable (5% open space)
- Cleaning with high pressure injection
- Low energy costs by gravity flow
- TSS-removal, P-Elimination



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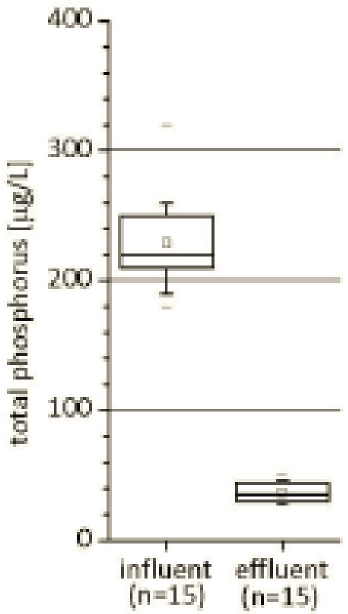
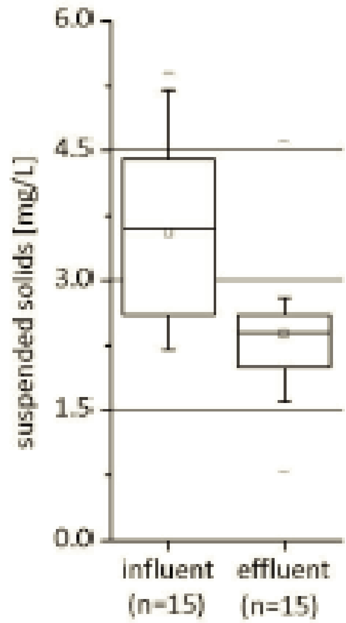
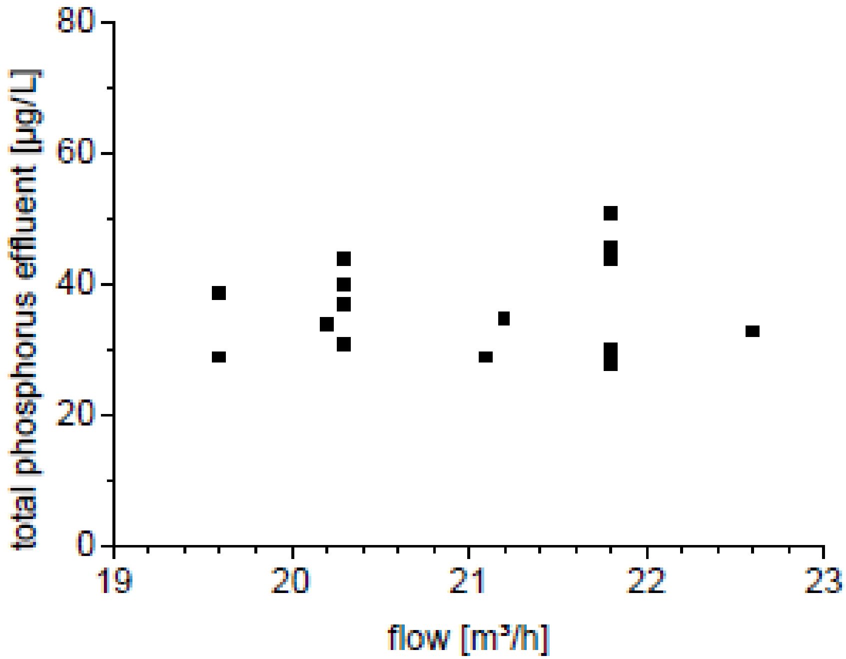
Results micro-sieve

- Pre-located two stage coagulation suitable to reached P effluent value < 0.08 mg/L.
  - E.g. with 2 mg/L PACl (Polyaluminiumchloride) and 0,6 mg/L FHM (flocculation agent) ➔ 0,06-0,065 mg/L



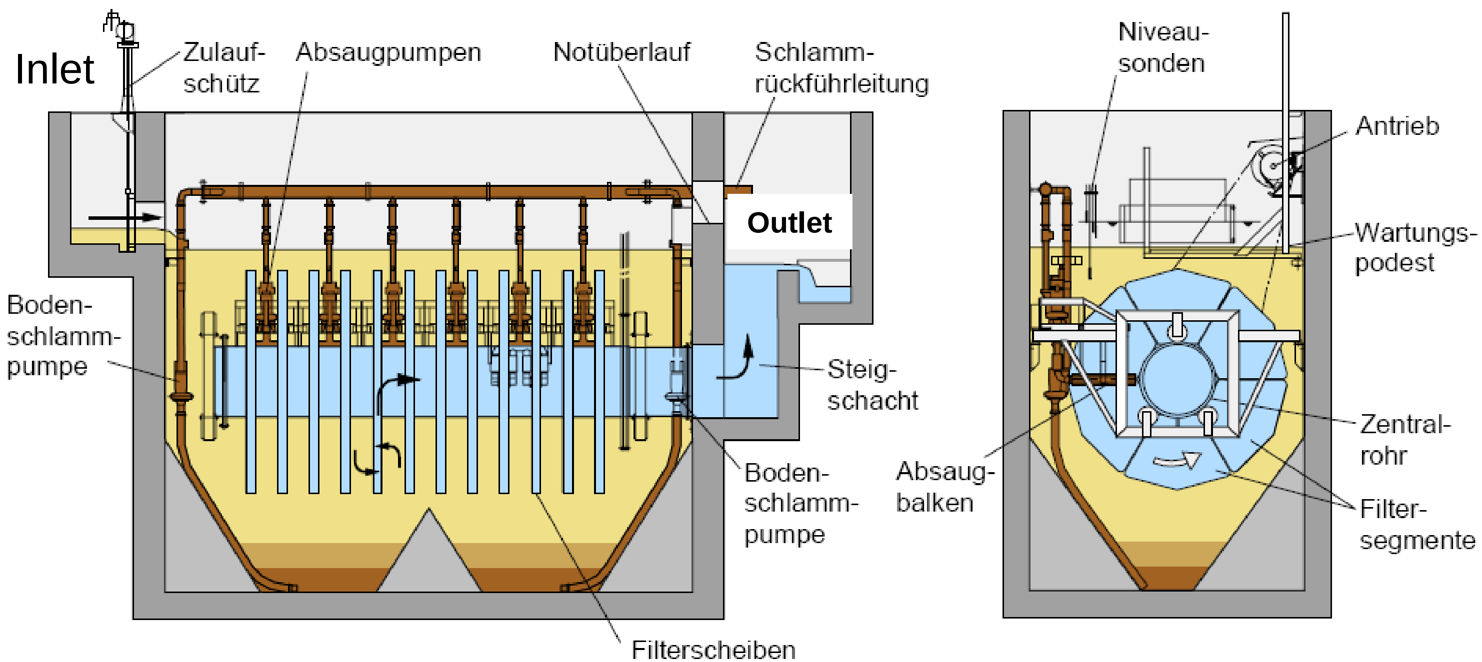




Lardon 2012

Cloth filtration
Disc-filter

- Formally small fibred needle felt cloth (width 10 – 10 µm)
  today Pile fabric
- Filter velocity $v_{F,DW,RW} \approx 10{,}0$ m/h
- Surface load of particles < 400 g/($m^2 \cdot h$); TSS_{in} max. 40 mg/l
- Suitable for TSS- and P-removal



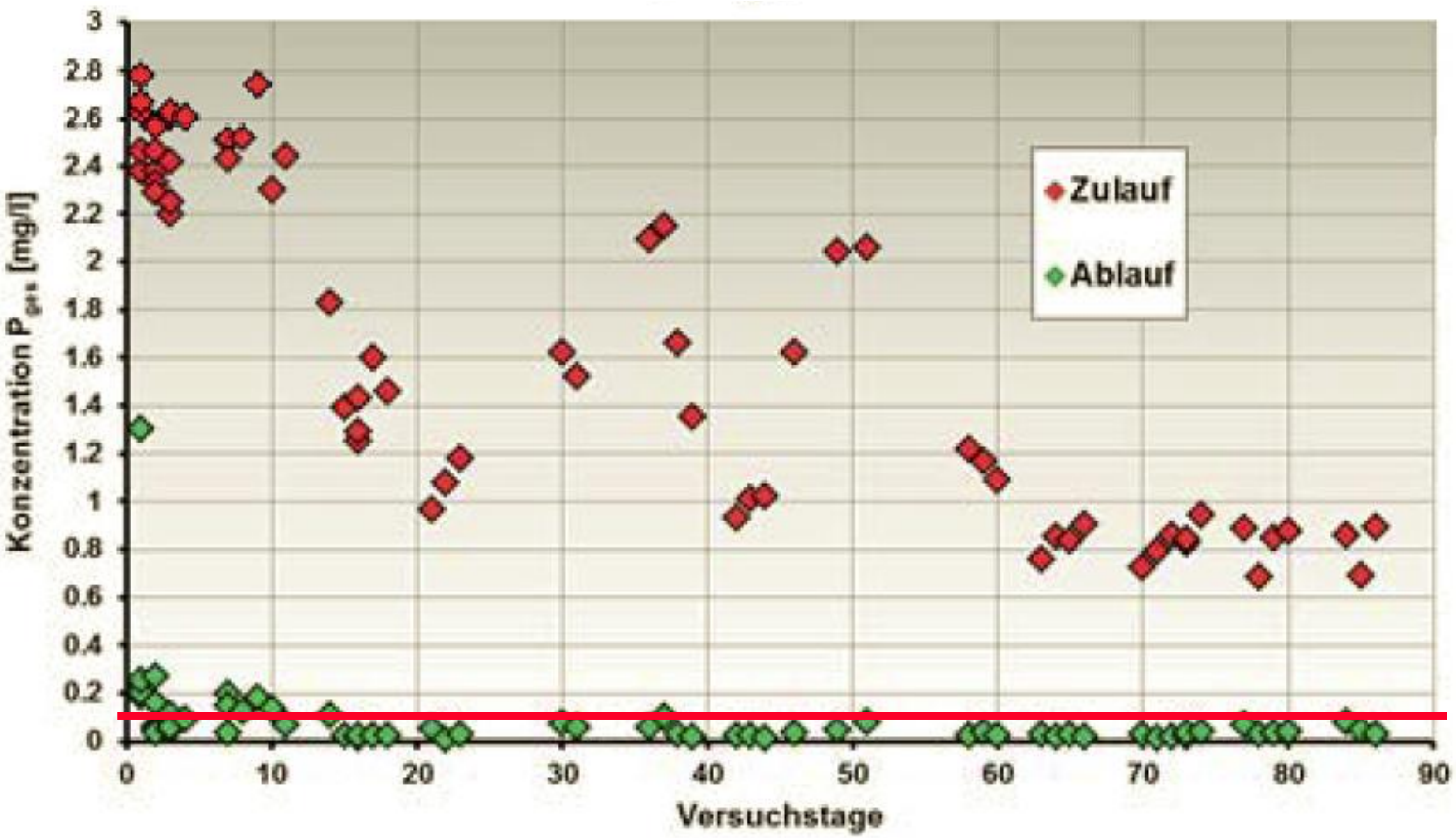
Basic space of drum filter: 3,8 m^2 A_F/m^2 A_{base}

Cloth filtration
Disc-filter; Example WTP Oldenburg

- 14 x 60m² Disc filter
- Total filter surface 840 m²
- Maximum flow: 5,800 m³/h
- Today world wide largest disc cloth filter
- Built in 2006
- Effluent < 5 mg/l TSS
- Microplastic removal

P-Elimination with cloth filtration

Pole fabric coated

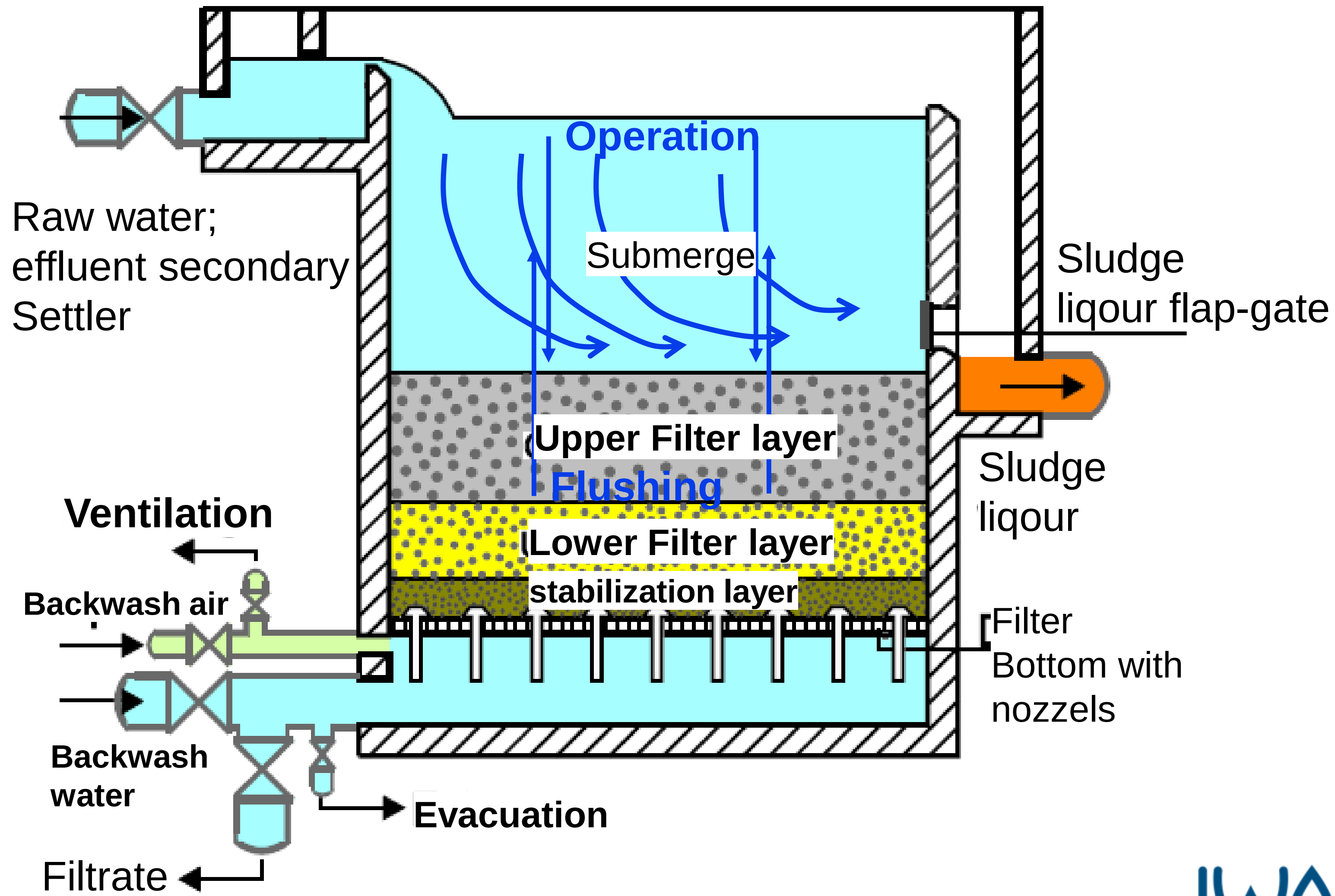


- Effluent < 0,1 mg/l P_{tot} with precipitation and pile fabric

Deep bed filter

Down-flow granular media filter

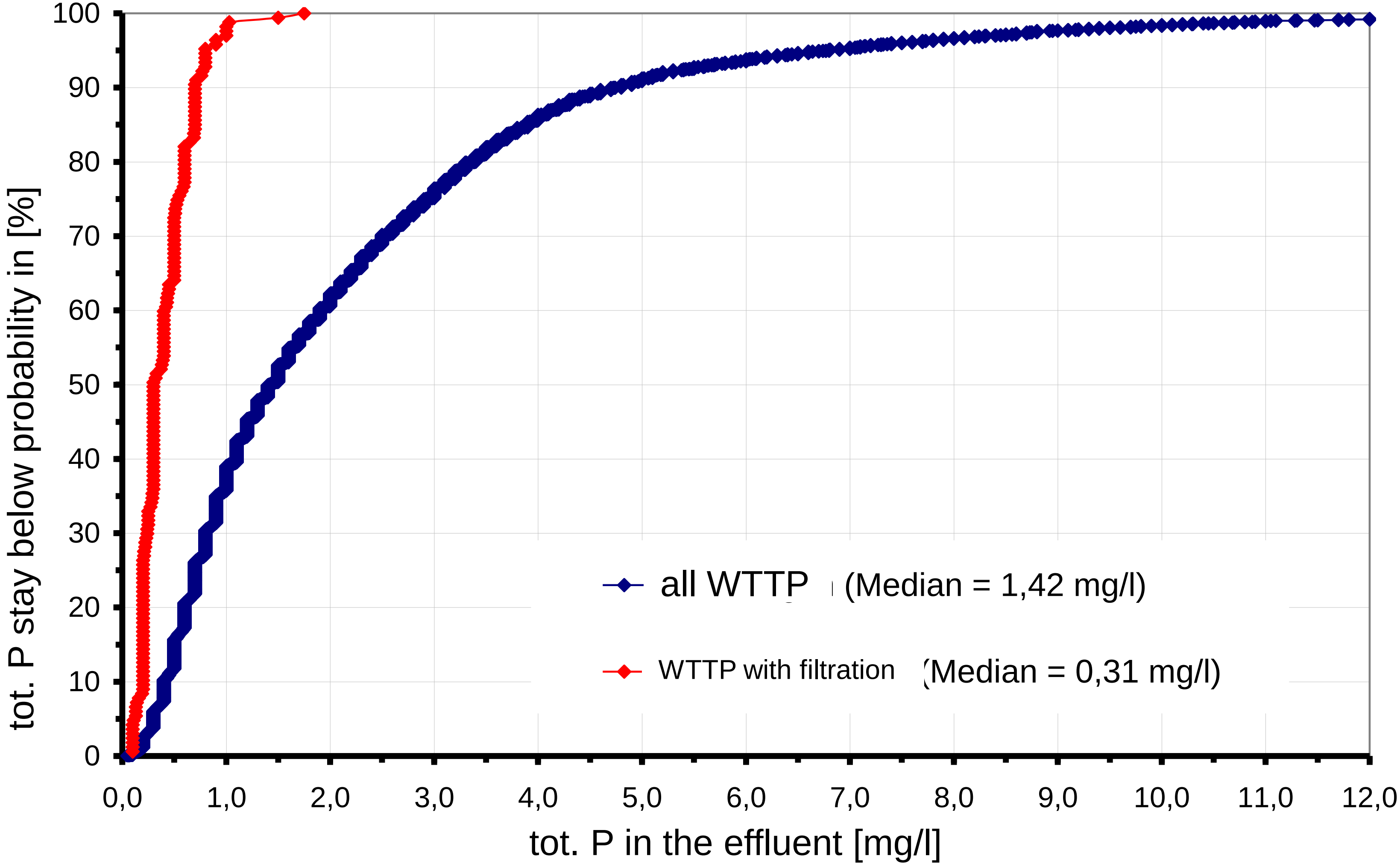
Intermediated backwashed by flap flushing



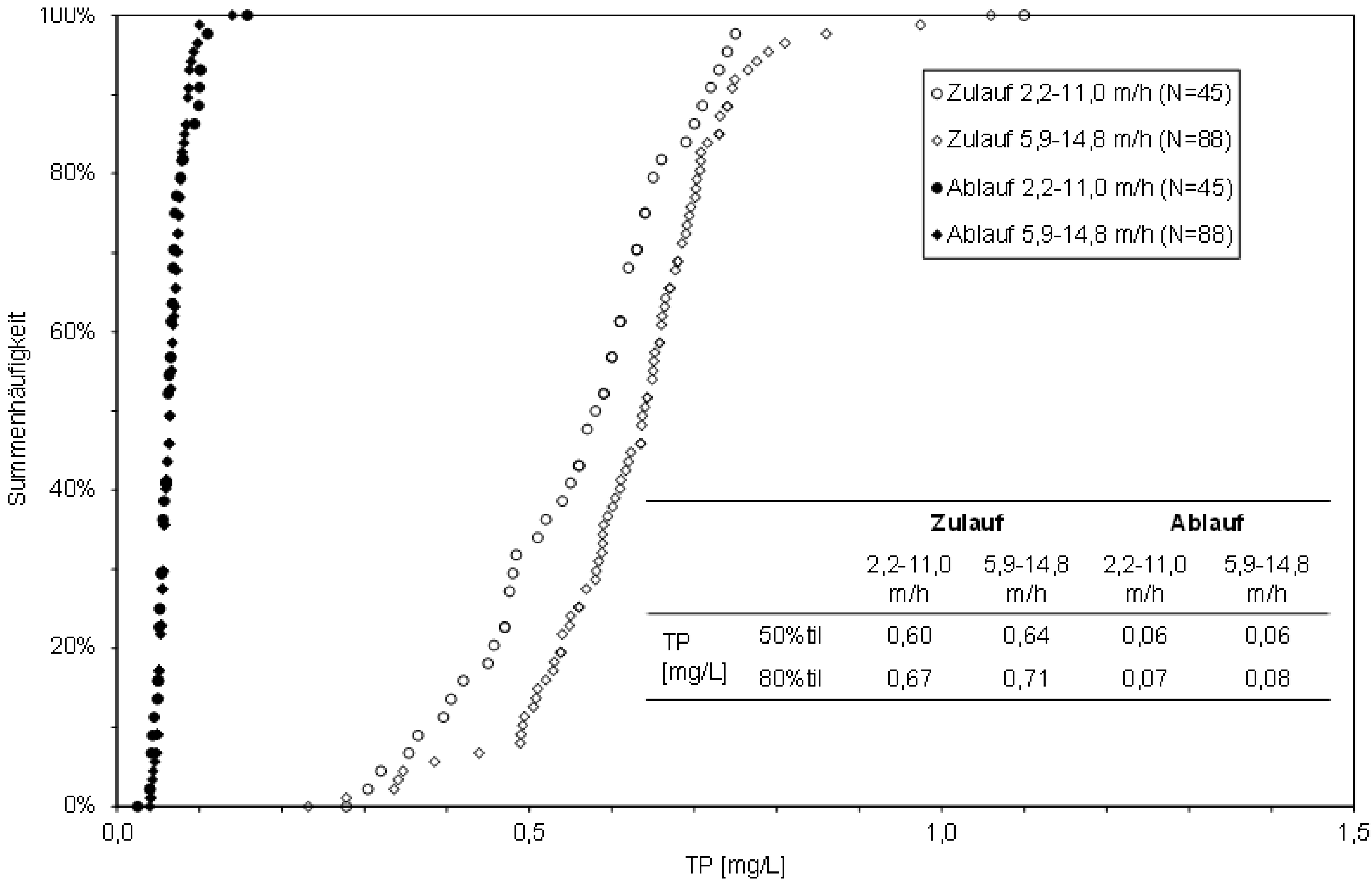
Down-flow granular media filter

Intermediated backwashed by flap flushing

Operational results of coagulation Filtration



Stay below probability TP-Concentration in In- and outlet of a coagulation filter Dosage of Fe^{3+} and different v_F



		Zulauf		Ablauf	
		2,2-11,0 m/h	5,9-14,8 m/h	2,2-11,0 m/h	5,9-14,8 m/h
TP [mg/L]	50%til	0,60	0,64	0,06	0,06
	80%til	0,67	0,71	0,07	0,08

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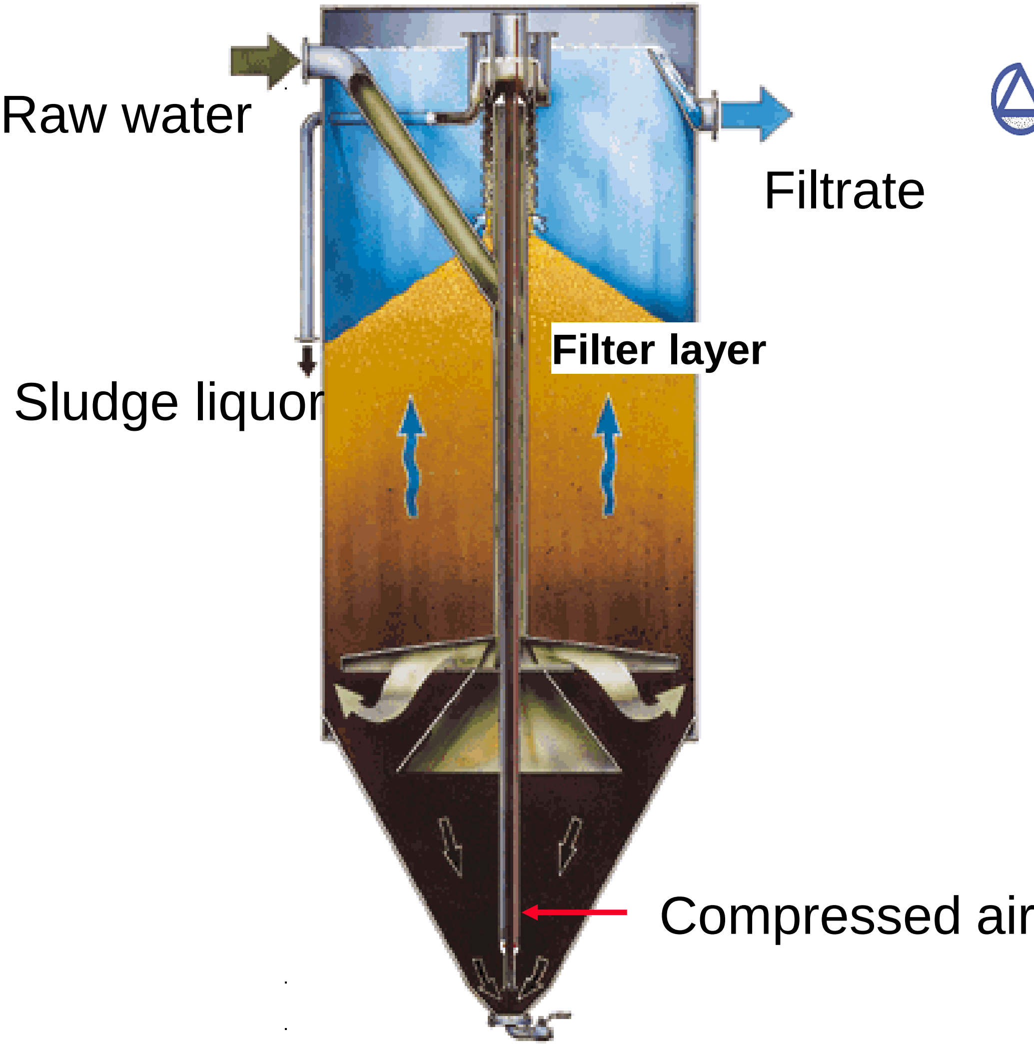
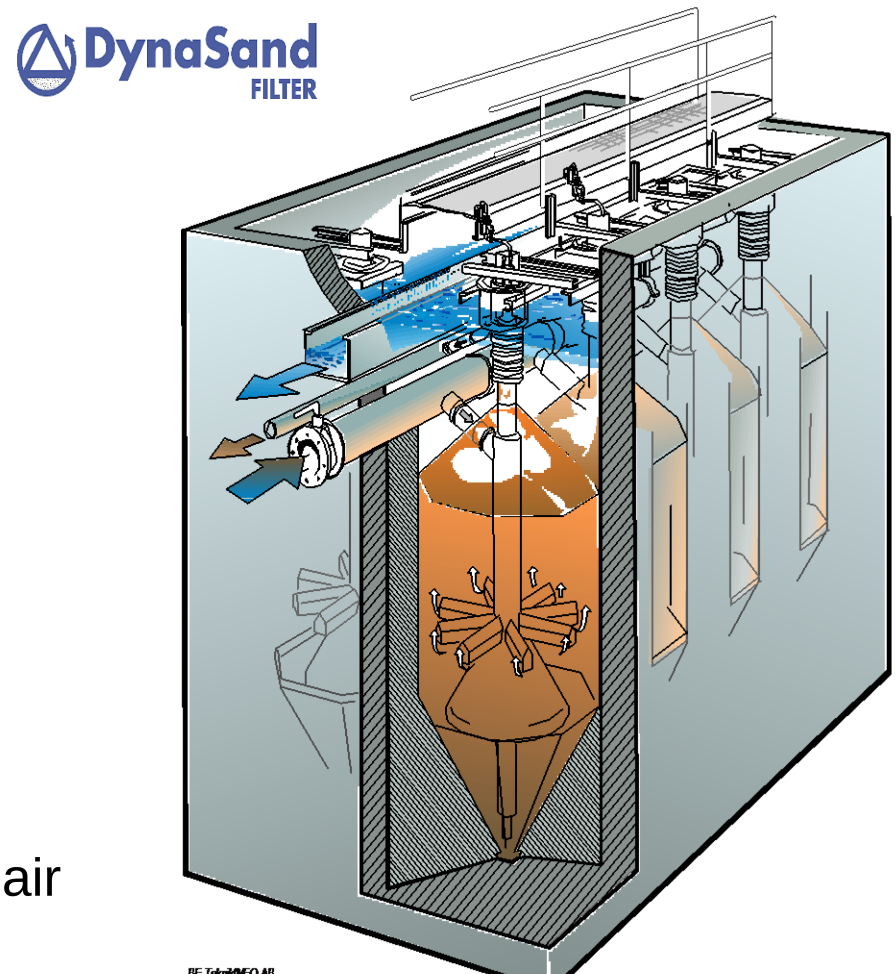
Continuously operating filter plants

Up-flow-Operation

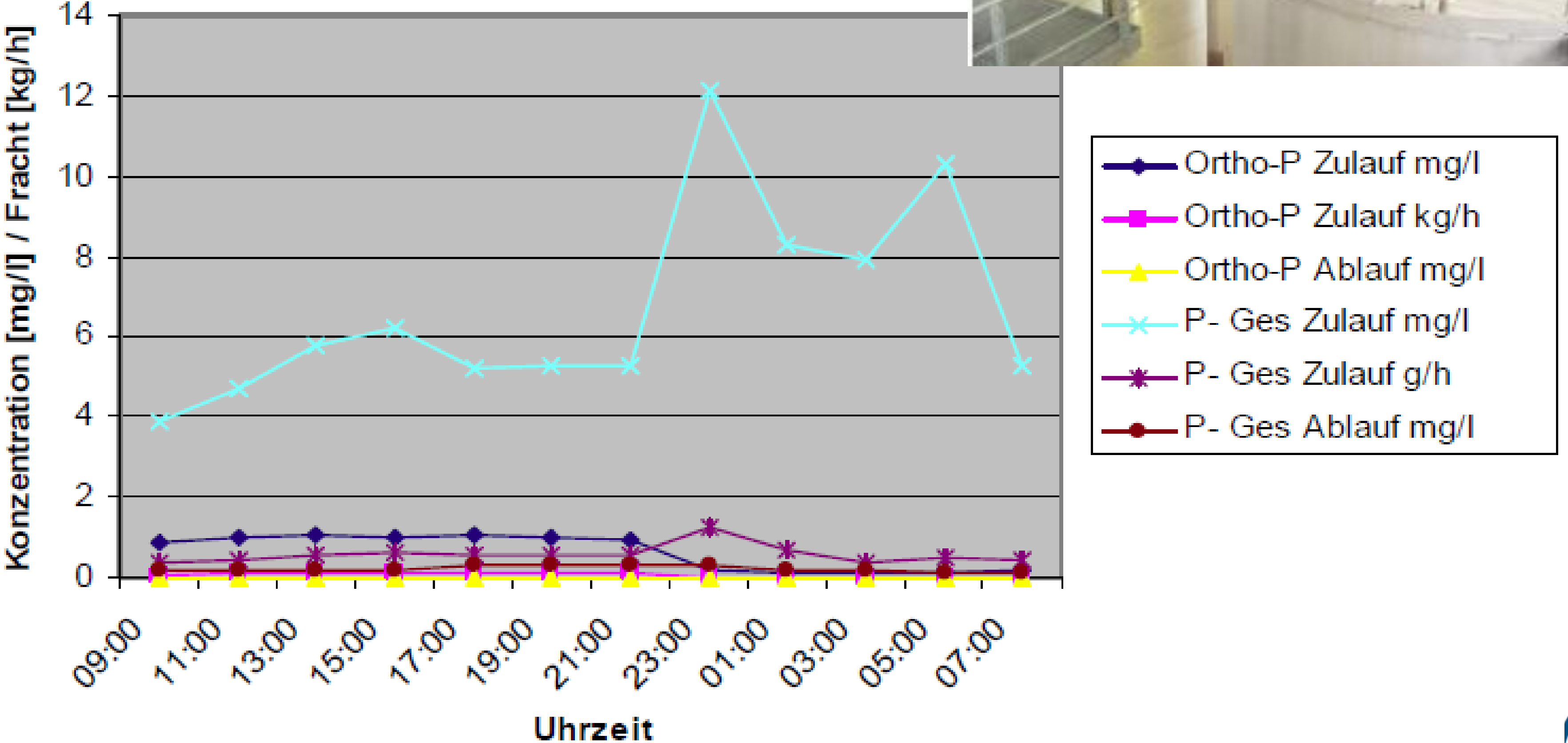




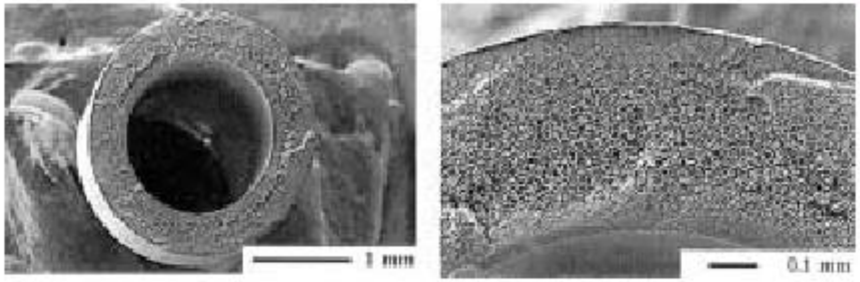
Interactive Water Management

Phosphorous removal

Example WTP Ratzeburg



Post located membrane filtration

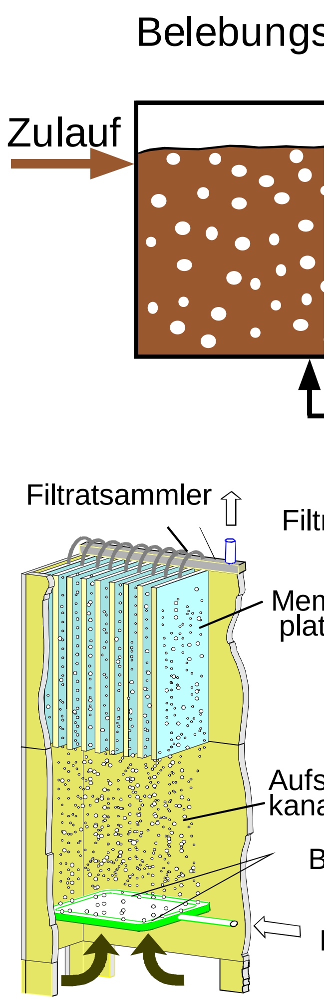


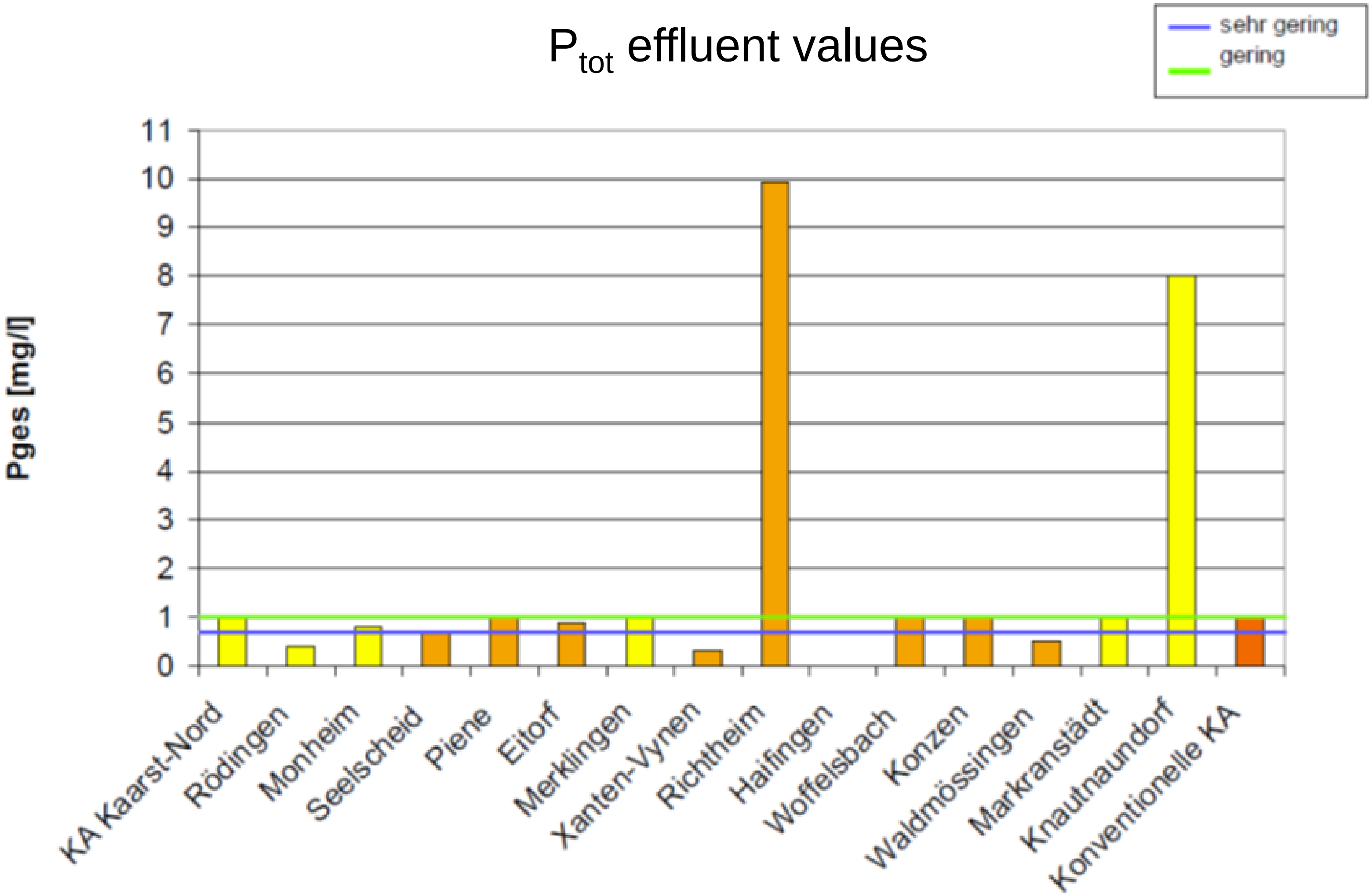
- Variants of modules
  - pipe-, capillary-, Hollow fibre and surface module)
  - Membrane material (organic - inorganic)
  - Pore size from 0,01 to 0,2 µm
  - Pre-located granulated filter necessary (removal of particles > 500 µm)
- Cleaning with gas ca. all 30 min.
- Flux-rate 41.6 l/(m^2·h) with 1.3 bar starting pressure
- Energy consumption: 0.2 kWh/m^3
- Results
  - TP-Concentration from 0.2 - 1 mg/L down to < 0,05 mg/L in the effluent; monthly average **0.025 – 0.045** mg/L
  - β-value = 2 – 5; no coagulant agents

Gnirss(2007)

TP-Effluent of Biomembrane reactor

Germany





In pratice< 0,3 mg TP/l possible

PINNEKAMP ET AL., (2008)

Thank you for your attention

Interreg
Baltic Sea Region

EUROPEAN UNION

EUROPEAN REGIONAL DEVELOPMENT FUND

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