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Biological treatment processes of water and waste
Lecture 8

WAT - E2180

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Lecture outline

Design of biological processes

- Removal of organic matter, nutrients and other compounds
- Design approaches
- Process configurations
- Important design aspects

- DEMO exercise: Dimensioning of anoxic zone for denitrification
- Micropollutant removal and antibiotic resistance in bioprocesses
- Nitrous oxide emissions

Preparation for the

Excursion to Viikinmäki WWTP

Design of biological processes

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Removal in biological processes

Removal	Conditions	When
Organic matter	Aerobic, short SRT	Focus on removal
Organic matter	Anaerobic, long HRT&SRT	for high strenght waters, focus on energy recovery
Ammonium (nitrification)	Aerobic, long SRT	Well known process
Total nitrogen Nitrification + denitrification	Aerobic + anoxic zones, Short/long SRT	Well known process
Total nitrogen Short-cuts	Low DO (nitritation + denitritation) Deammonification	Focus on energy savings High strength waters
Phosphorus	Aerobic + anaerobic zones	P reuse, sludge production, carbon source
NOM, iron, manganese, organic micropollutants	Aerobic, mainly long SRT	Often cost effective solution

Design approaches for biological processes

Sludge age (days) → Sludge age selected on the basis of process goals (e.g. nitrification) → Basin volume

Sludge loading (kgBOD/kgMLSSd) → As above but does not take into account differences in sludge yield (e.g. process design when water is very typical)

Volumetric loading (kgBOD/m^{3}d) e.g. rough estimations for bugdeting

Surface loading (kgBOD/m^{2}d or kgN/m^{2}d) MBBR and biological filters

Reaction rate (gN/gMLSSh) e.g. anoxic zones

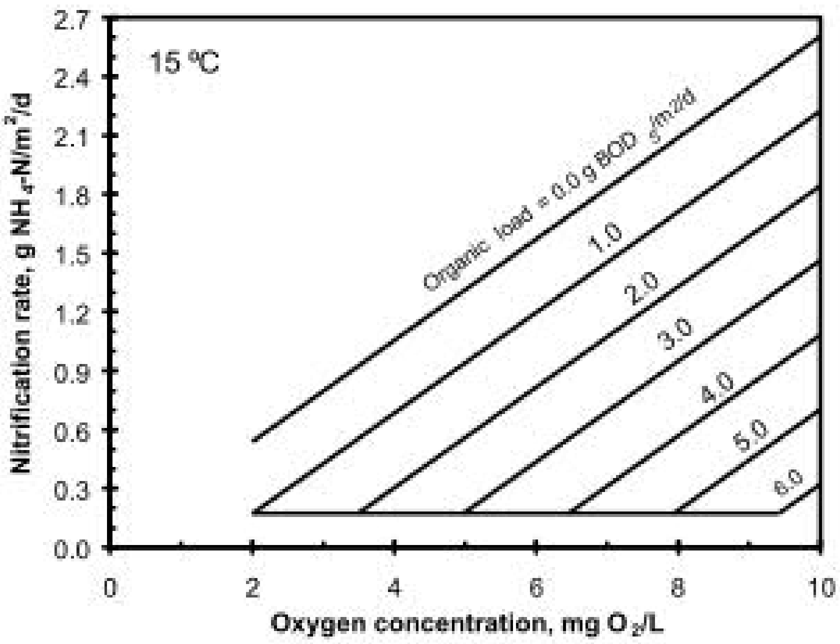
Hydraulic retention time (hours) e.g. anaerobic and anoxic zones

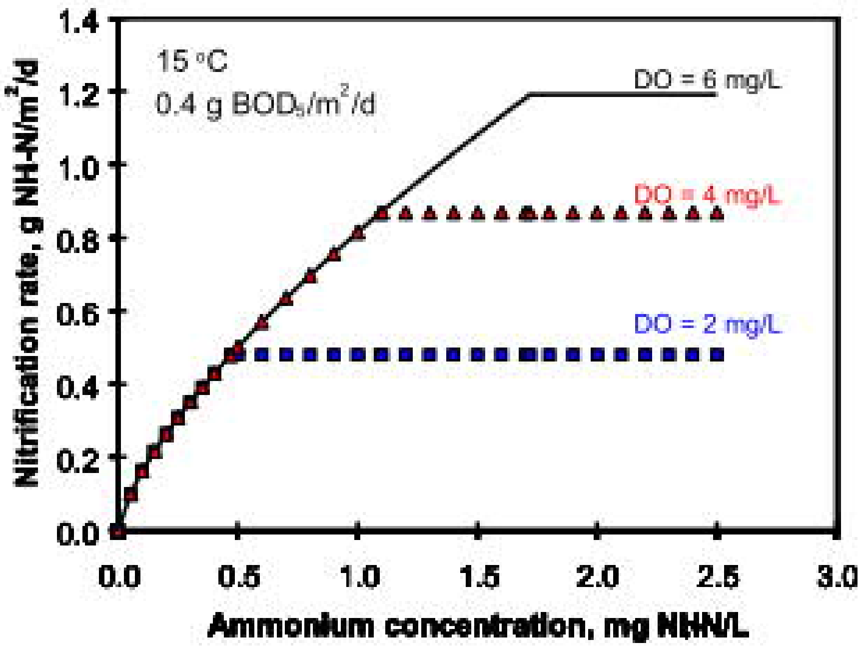
Example: Dimensioning of the anoxic volume (denitrification)

- **Retention time minimum 0,5 – 2 h**
- **To be checked based on the carbon source**

Carbon source	g N / kgVSSh		
	7 °C	14 °C	20 °C
Raw WW	0,6	1,5	3
Primary settled WW	0,6	1,5	3
Pre-fermented WW	1-2	2-5	5-10
Acetic acid	2	5	10
Methanol	2	5	10

Example: Nitrification in MBBR





- Odegaard 2014

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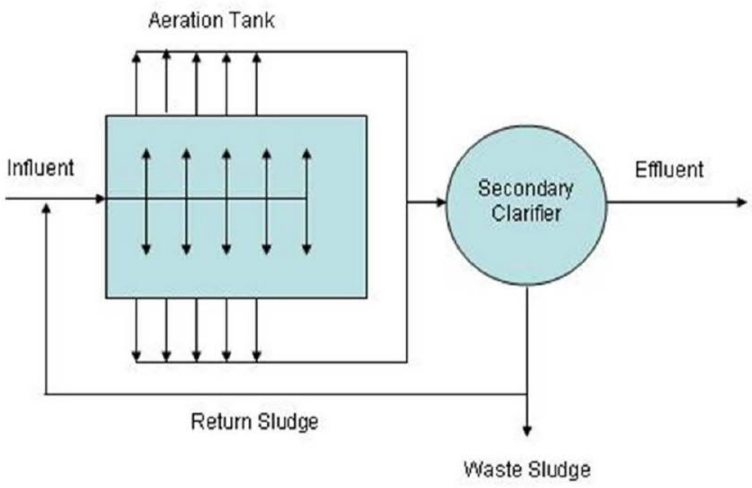
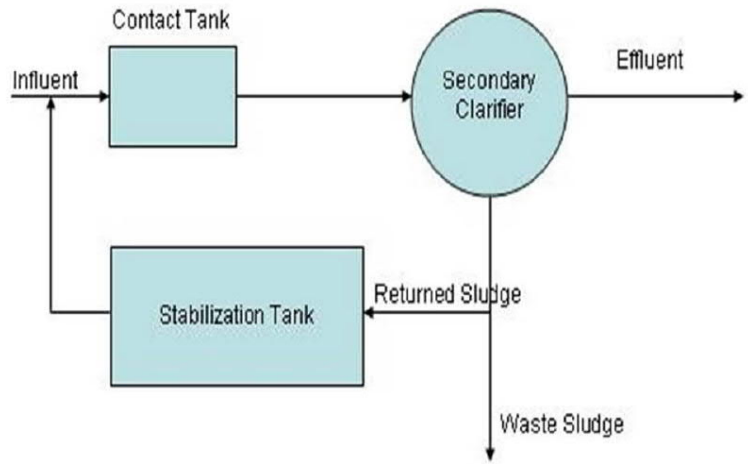
More design examples in HW4&5

Important design aspects

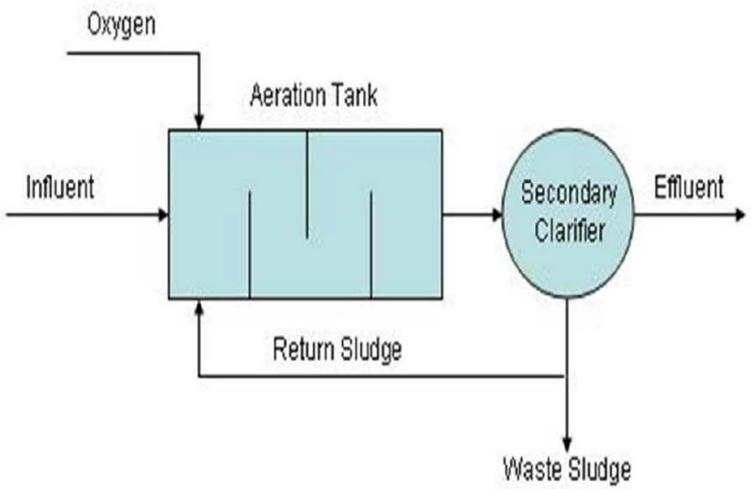


Complete Mix Activated Sludge Process

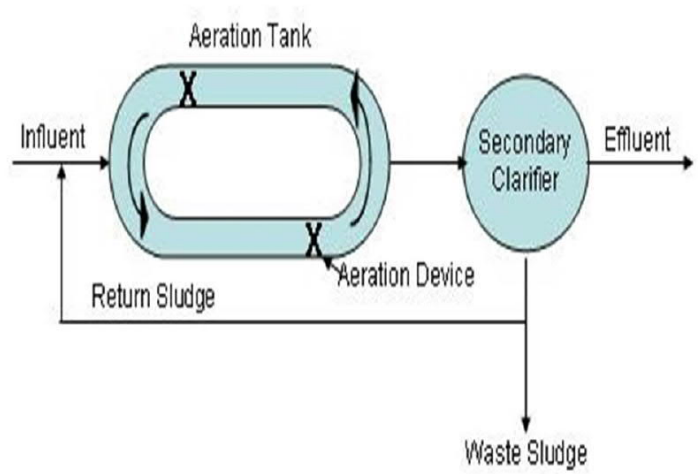


Contact Stabilization Activated Sludge

Intensive or extended aeration

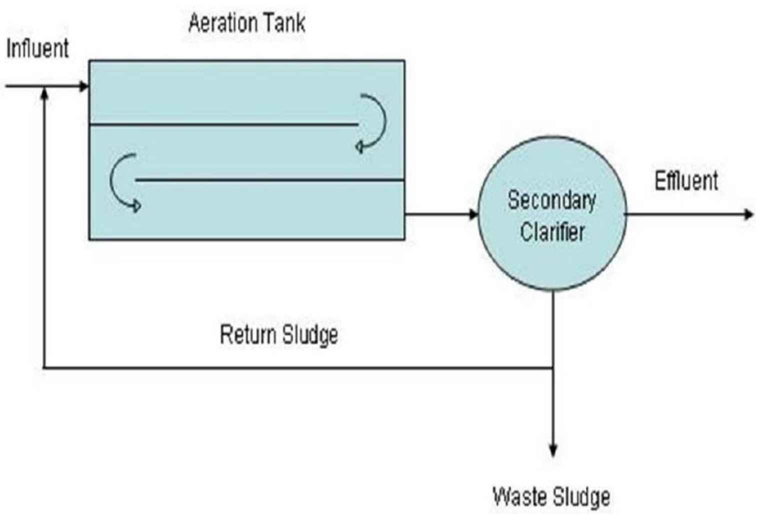


High Purity Oxygen Activated Sludge

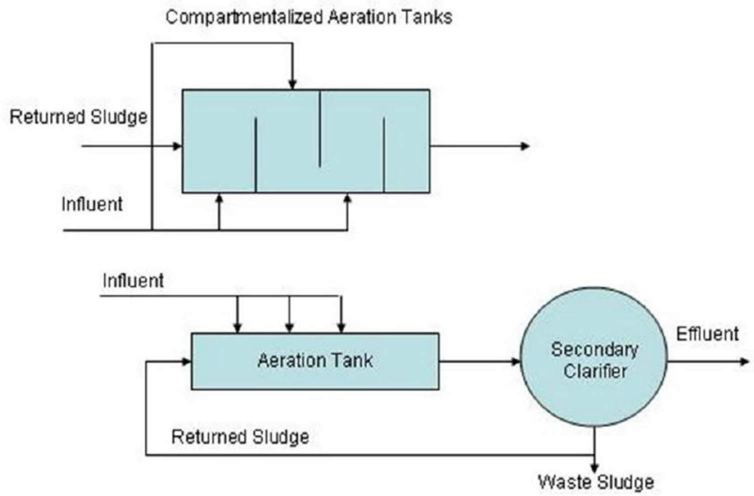


Oxidation Ditch Activated Sludge Process

Process configurations

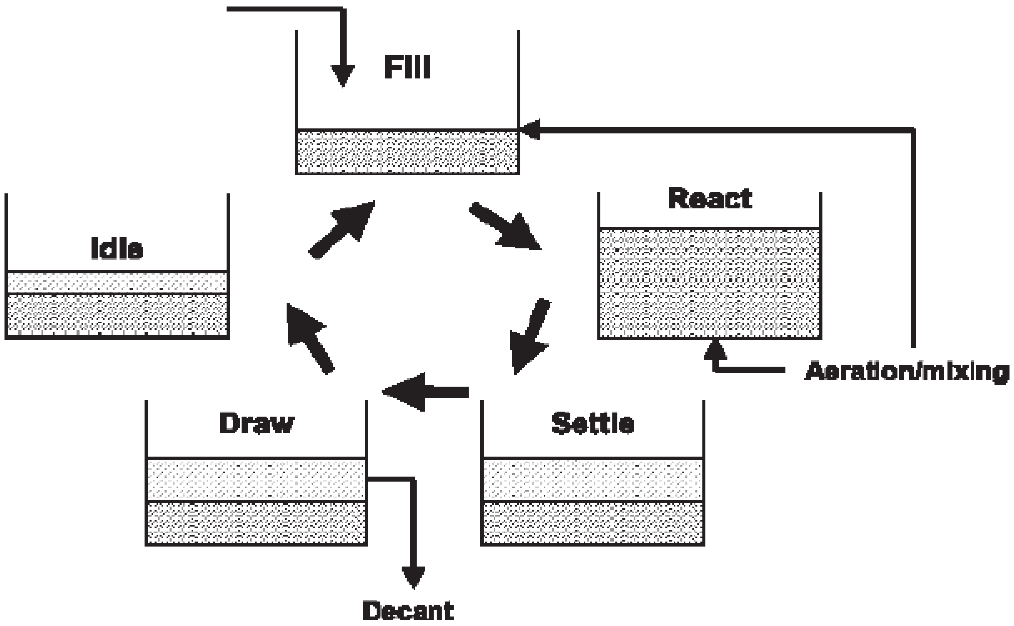


Plug Flow Activated Sludge Process



Step Feed Activated Sludge Process

Process configuration



Sequencing batch reactor

All reactions happen in the same volume

Typically 2 or 3 parallel SBRs

Process type

Activated sludge
Moving bed bioreactor (MBBR)
Membrane bioreactor (MBR)
Biological filters
Aerobic granular sludge (AGS)

Selection depends on wastewater characteristics, climate conditions, energy aspects, effluent requirements, size etc.

Nitrogen and phosphorus removal

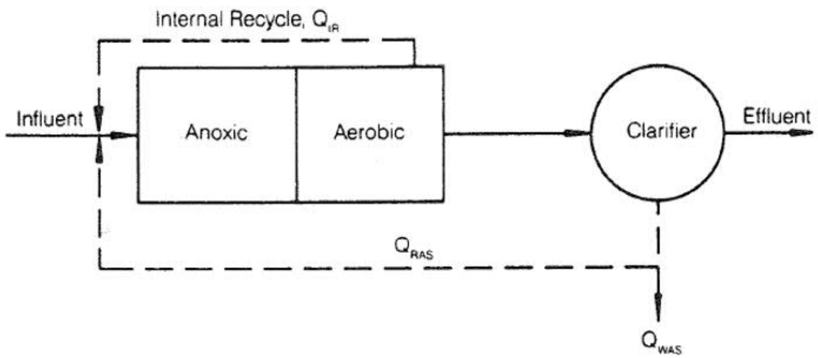


Figure 8.9 Modified Ludzack–Ettinger process for nitrogen removal (WAS = waste activated sludge).

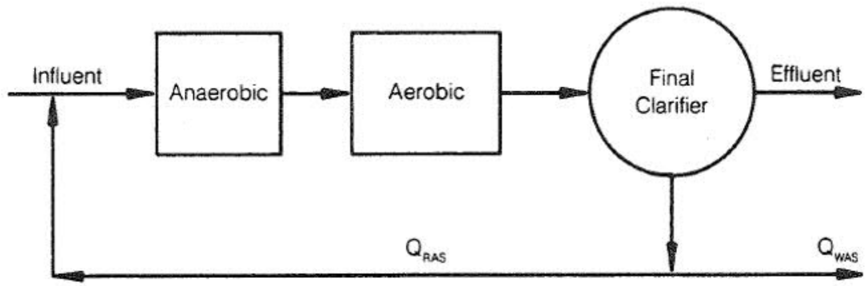


Figure 8.3 The A/O process (RAS = return activated sludge, WAS = waste activated sludge).

Alternative configurations

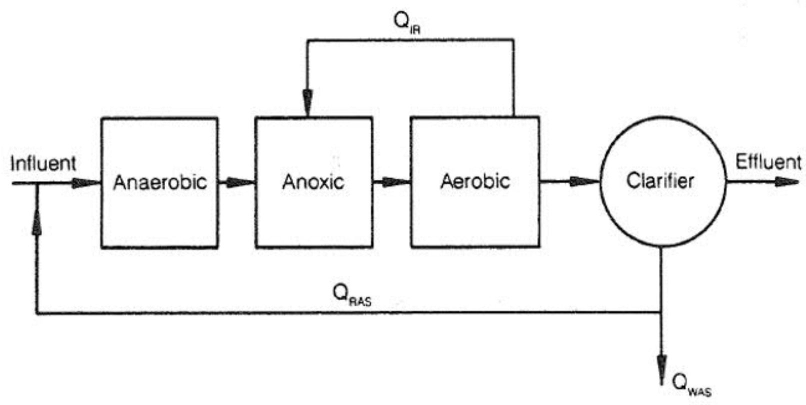


Figure 8.14 A²/O process for phosphorus removal (WAS = waste activated sludge).

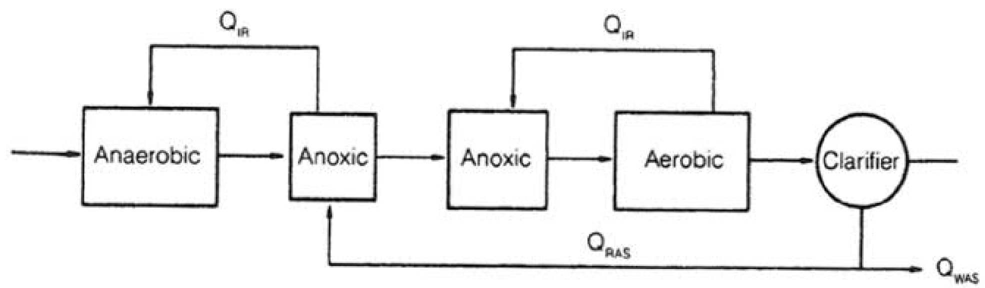


Figure 8.15 Modified University of Cape Town process for phosphorus and nitrogen removal (WAS = waste activated sludge).

How to calculate the recycle ratio of RAS?

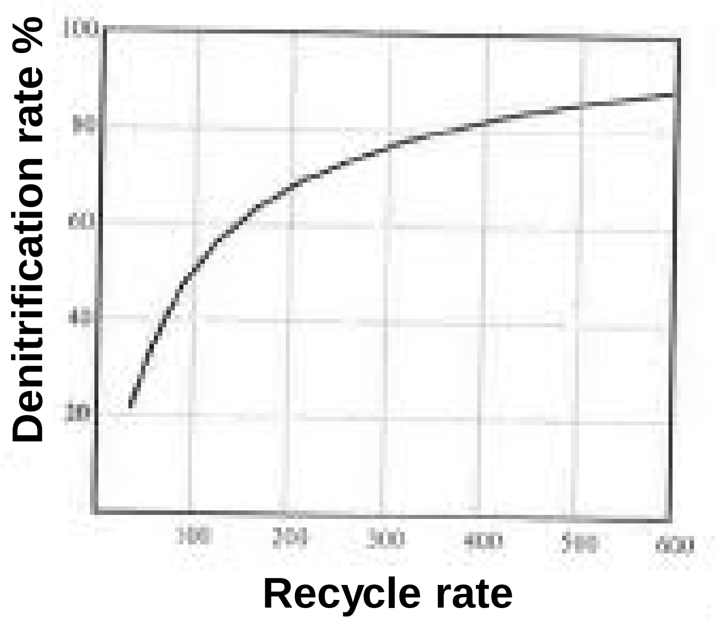
Recycle ratio = 100X / ((1200/SVI) - X)

Where X = MLSS (g/l)

And SVI = sludge volume index (ml/g)

Recycle must be sufficient for denitrification

Typical recycle ratio 100 - 200 %



Aeration design

- **Actual oxygen requirement AOR is calculated based on oxygen needed for oxidation of organic matter, nitrification and endogenous respiration.**
- **If the process contains denitrification, AOR is decreased by the oxygen provided by nitrates.**
- **Oxygen transfer rate is determined taking into account oxygen transfer (wastewater characteristics)**
- **Air flow is calculated using standard oxygen transfer efficiency SOTE of a specific aeration equipment.**

:

DEMO 1

Average daily flow rate	37 850 m3/d
Influent water:	
BOD7	140 mg/l
Ammonium-N	35 mg/l
Suspended solids Of which unbiodegradable	90 mg/l 30 mg/l
Effluent water:	
BOD7	10 mg/l
Ammonium-N	0,5 mg/l
Total N	10 mg/l
Suspended solids	15 mg/l
Temperature	12 C
MLVSS/MLSS	0,8
MLVSS	2,4 g/l
Y (heterotrophs)	0,6 kg VSS/kg BOD
b (12 C)	0,044 d-1
Y (nitrifiers)	0,12 kg VSS/kg NH4-N
bN (12 C)	0,06 d-1

Dimension a denitrification step (pre-DN) for 70% total nitrogen removal. Calculate the volume based on denitrification rate for raw wastewater.

Calculate the recycle rate needed assuming SVI of 200 ml/g and the hydraulic retention time.

Dimensioning of the anoxic volume (denitrification)

Carbon source	g N / kgVSSh		
	7 °C	14 °C	20 °C
Raw WW	0,6	1,5	3
Primary settled WW	0,6	1,5	3
Pre-fermented WW	1-2	2-5	5-10
Acetic acid	2	5	10
Methanol	2	5	10

DEMO 1

The volume needed for denitrification is calculated based on the denitrification rate.

Assumption 1: No nitrate in the influent water

Assumption 2: No denitrification in the secondary clarifiers.

Total N 70 % → to be denitrified 927 kg/d = 38,6 kgN/h = 38 600 gN/h

Denitrification rate (12C, raw WW)→ 1,5 gN/kgVSS/h

MLVSS 2,4 g/l → needed volume 10 722 m^3

Recycle ratio (%) : = 100*3 / ((1200/200) - 3) = 100%

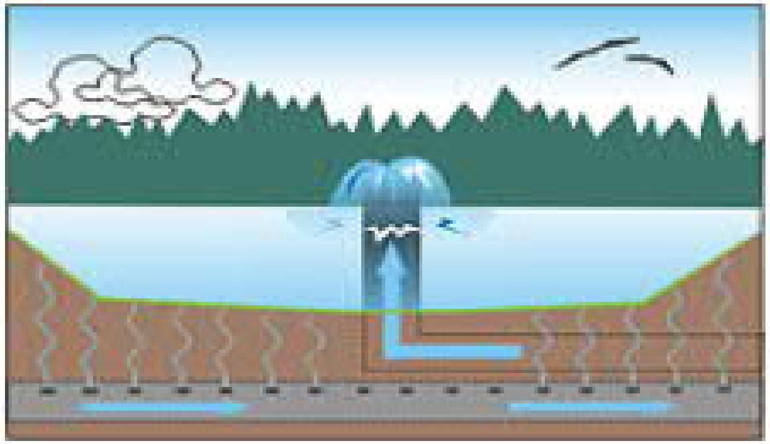
Hydraulic retention time in the anoxic zone

10722 m^3/ (2*1577 m^3/h) = 3,4 hours

Biological processes in drinking water treatment

Example: Slow sand filtration in Vaasa

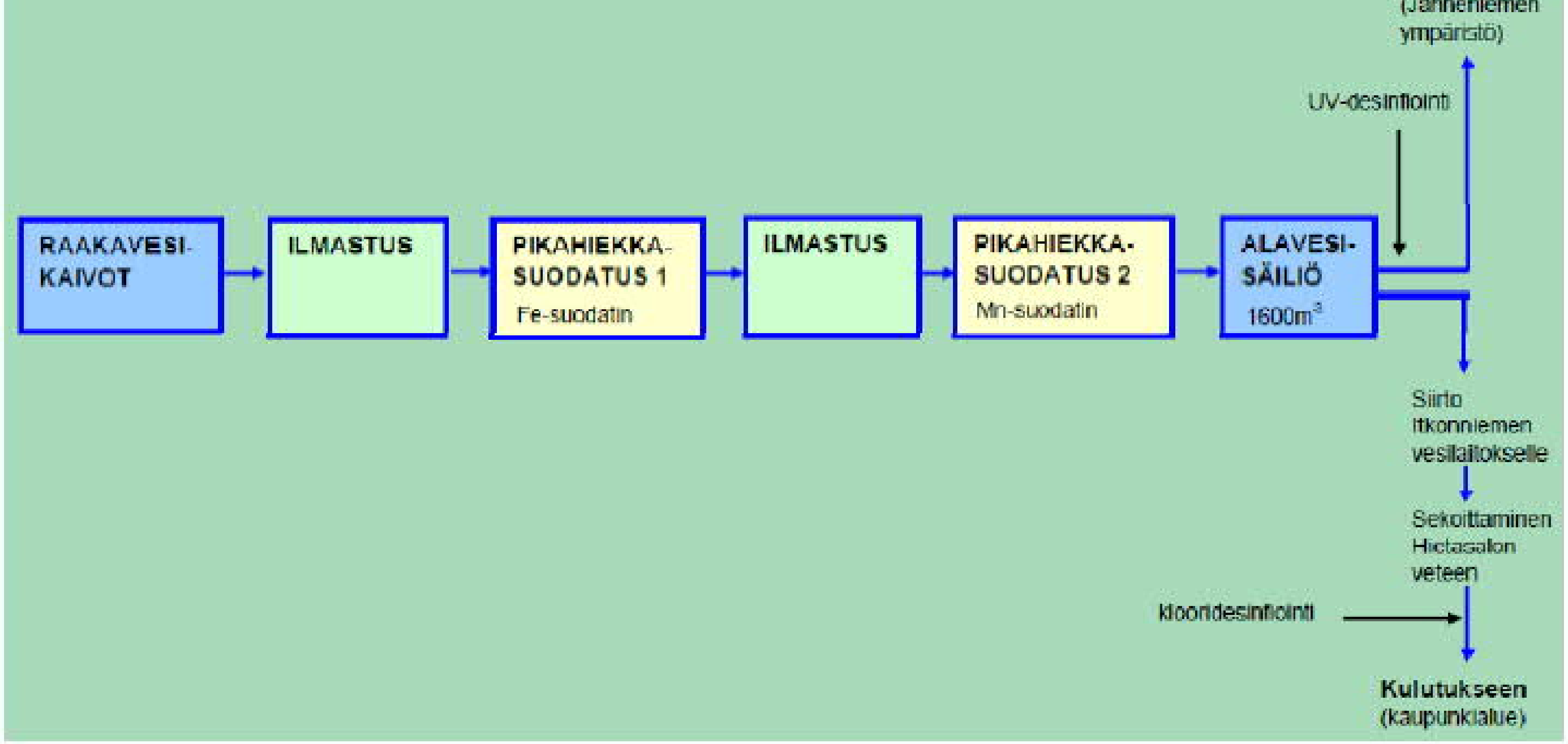
- **Water flows slowly through the sand layer (retention time 10 hours)**
- **Based on bacteria that grow on the sand**
- **Removal of taste and odour**



Biological processes in drinking water treatment

Example: Kuopio Rapid sand filtration

Biological removal of iron and manganese



Kuva 14. Kuopion Jänneniemen pikahiekkasuodatuslaitos (Lehtola ym, 2008).

Biological processes in drinking water treatment

Example: Biological activated carbon filtration
Biological removal of organical matter and emerging pollutants

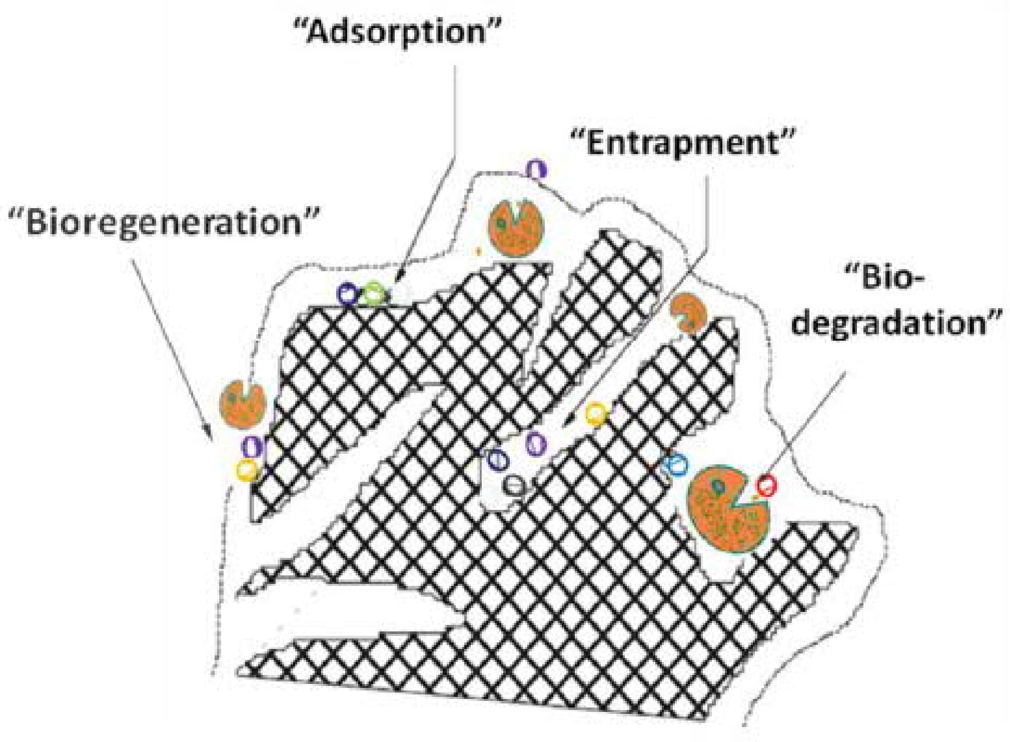


Figure 7: Biological Activated Carbon removal mechanisms. Adapted from Simpson (2008).

Excursion to Viikinmäki WWTP

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EXCURSION

To Viikinmäki wastewater treatment plant

THURSDAY 28.3. during the course teaching session

Some assignments during the visit

Using public transportation

COMPULSORY

Pictures: HSY

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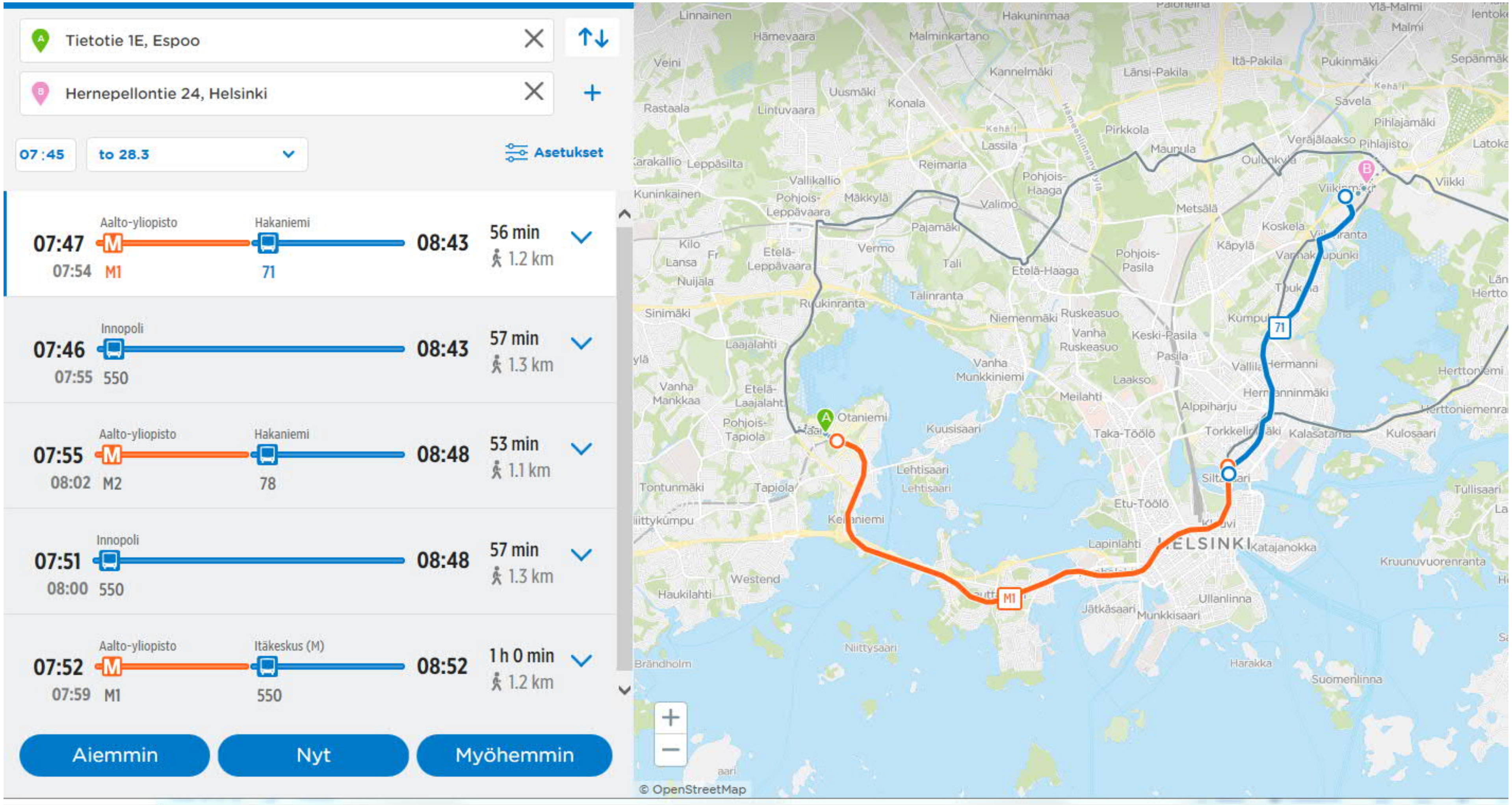
Viikinmäki WWTP

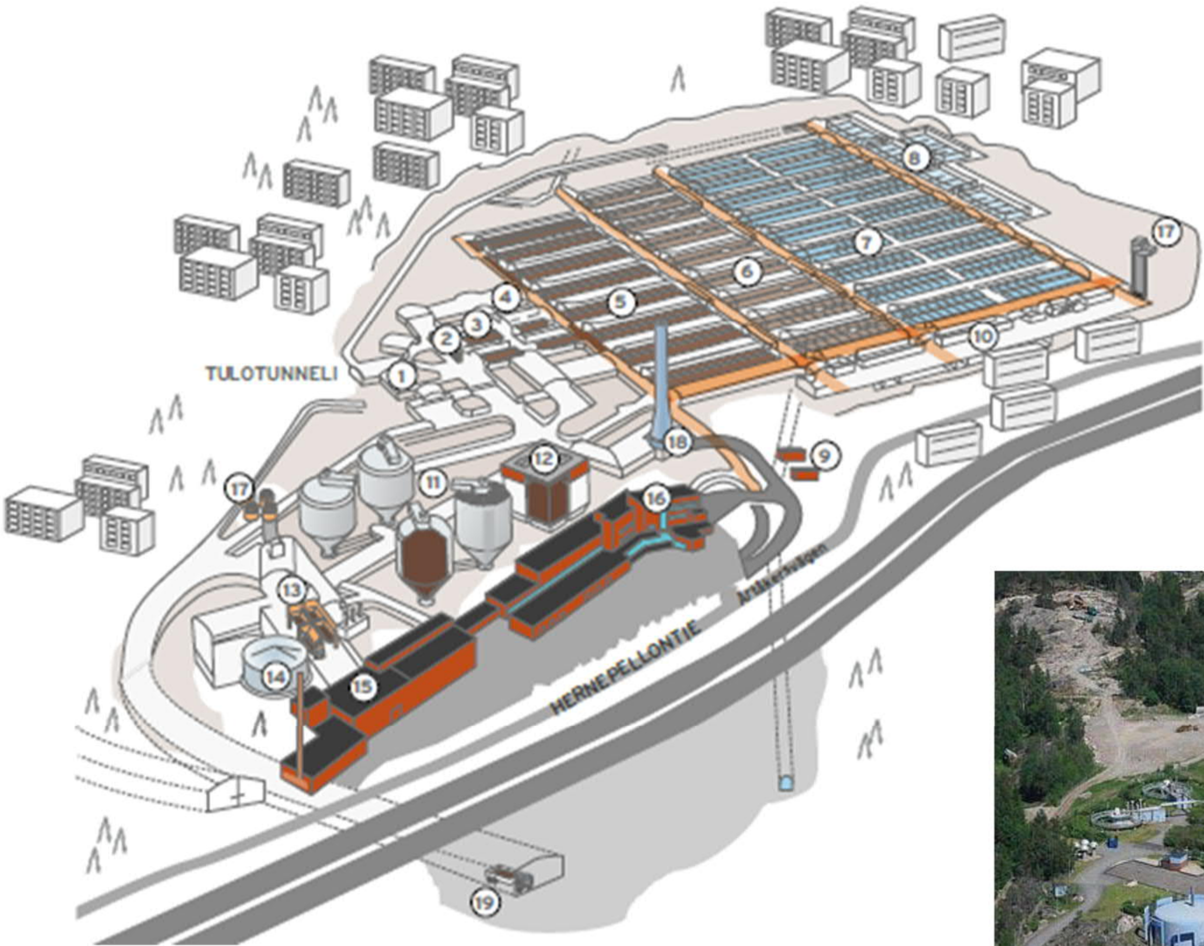
Address: Hernepellontie 24

We'll meet at 8:45

at the main entrance

How to get there?




TULOTUNNELI
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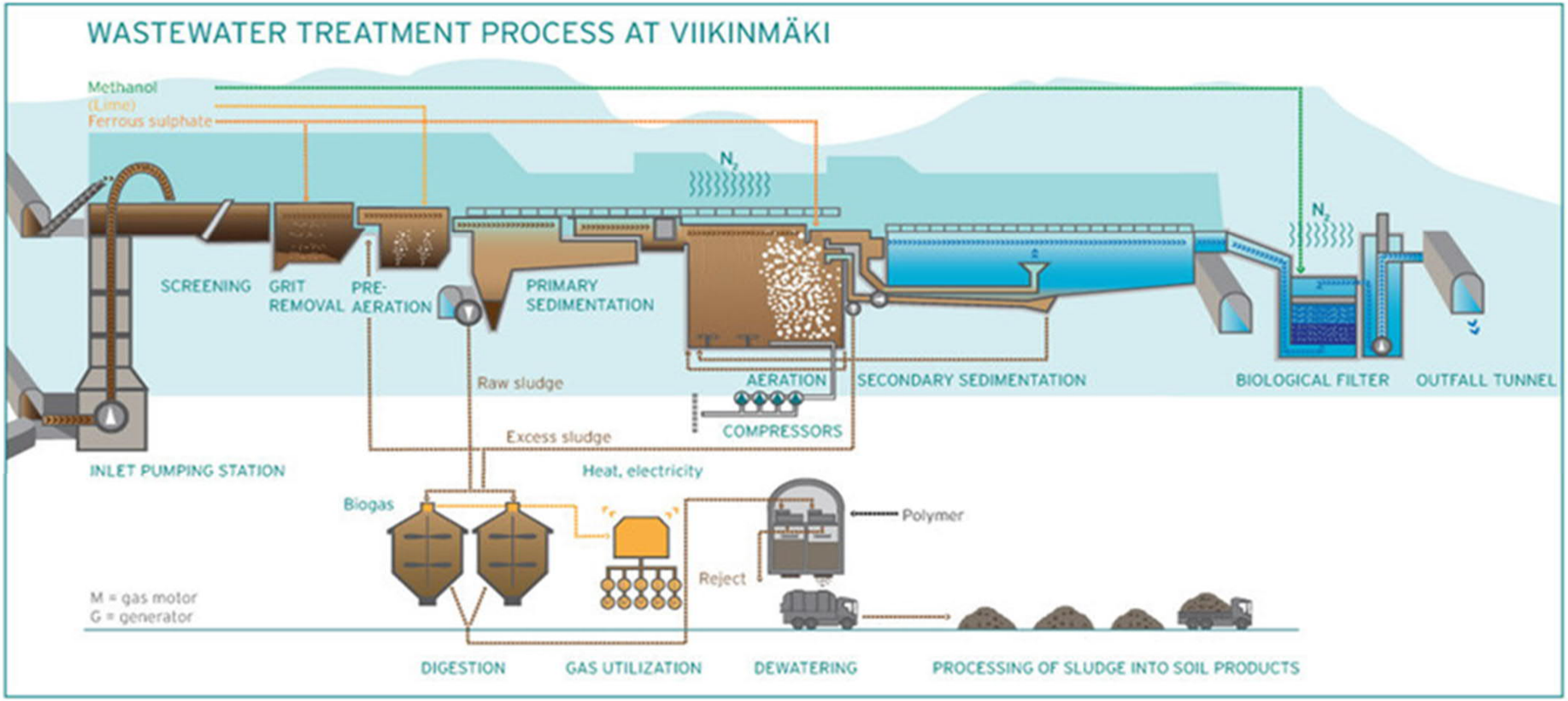
Process in Viikinmäki WWTP



WWTPCatching

Each student will receive a hint that you need to place somewhere in the process.

More info in Viikinmäki on Thursday ☺

Research on N_2O emissions

”Four years of on-line gaseous N_2O emission monitoring at a large WWTP - lessons learned and mitigation strategy outline “

HSY

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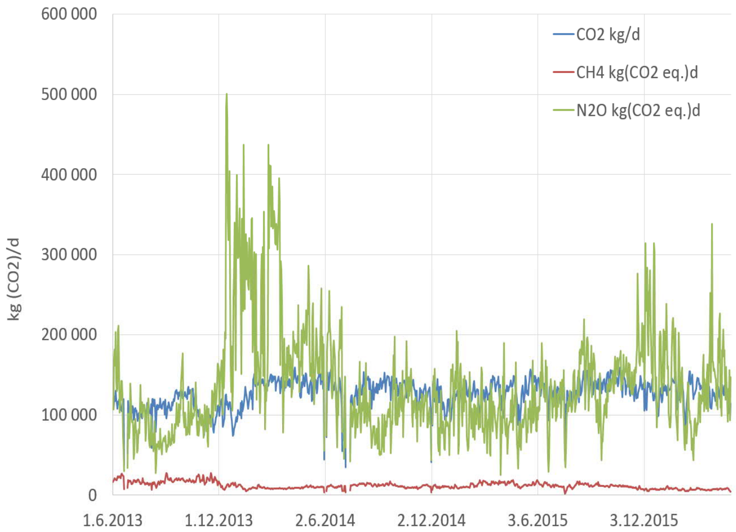
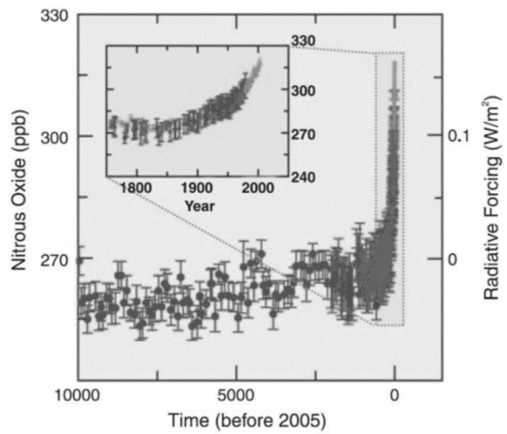
N_2O and wastewater treatment

300 times stronger greenhouse gas compared to CO_2

Produced in the biological nitrogen removal

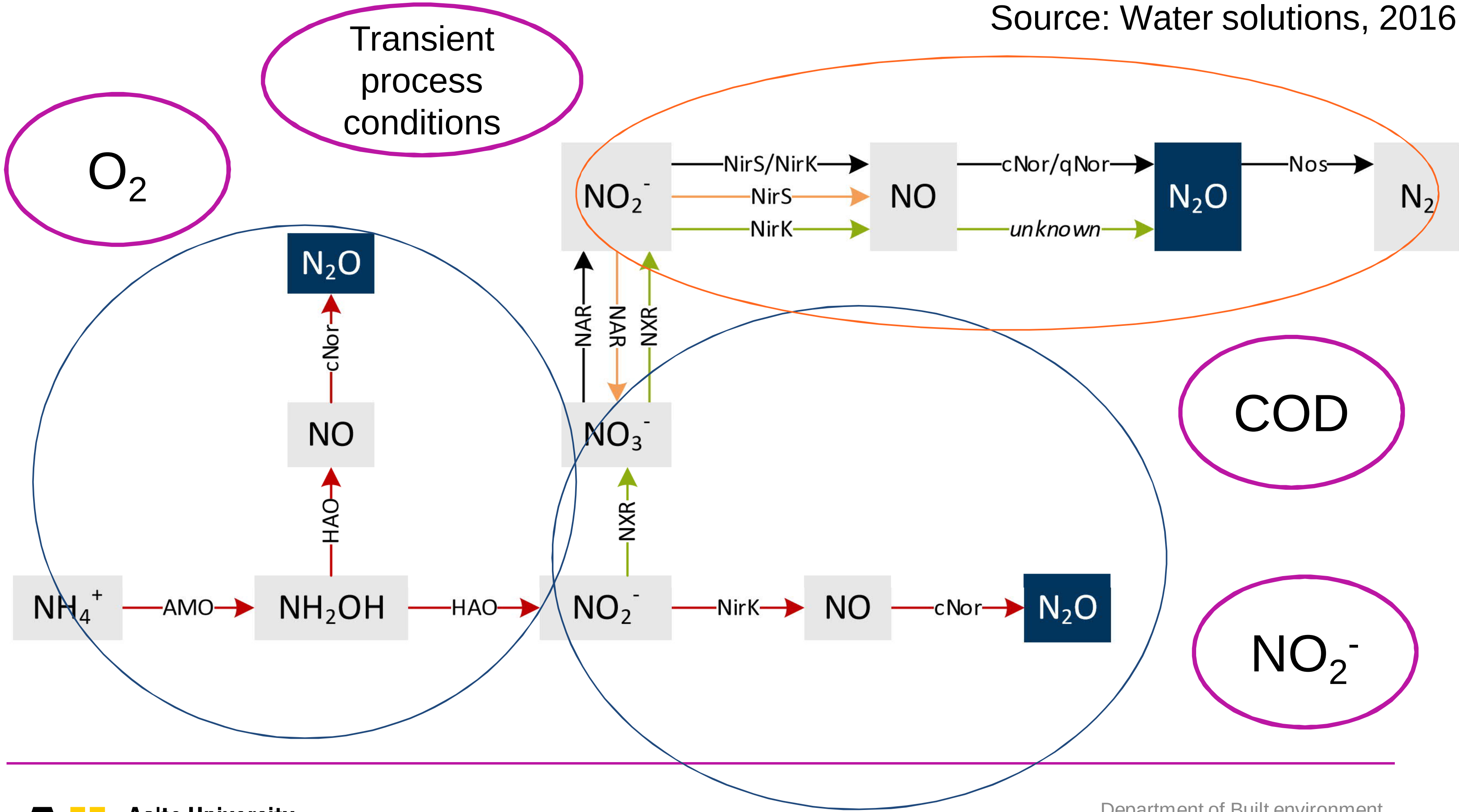
Often the most significant greenhouse gas emitted in wastewater treatment



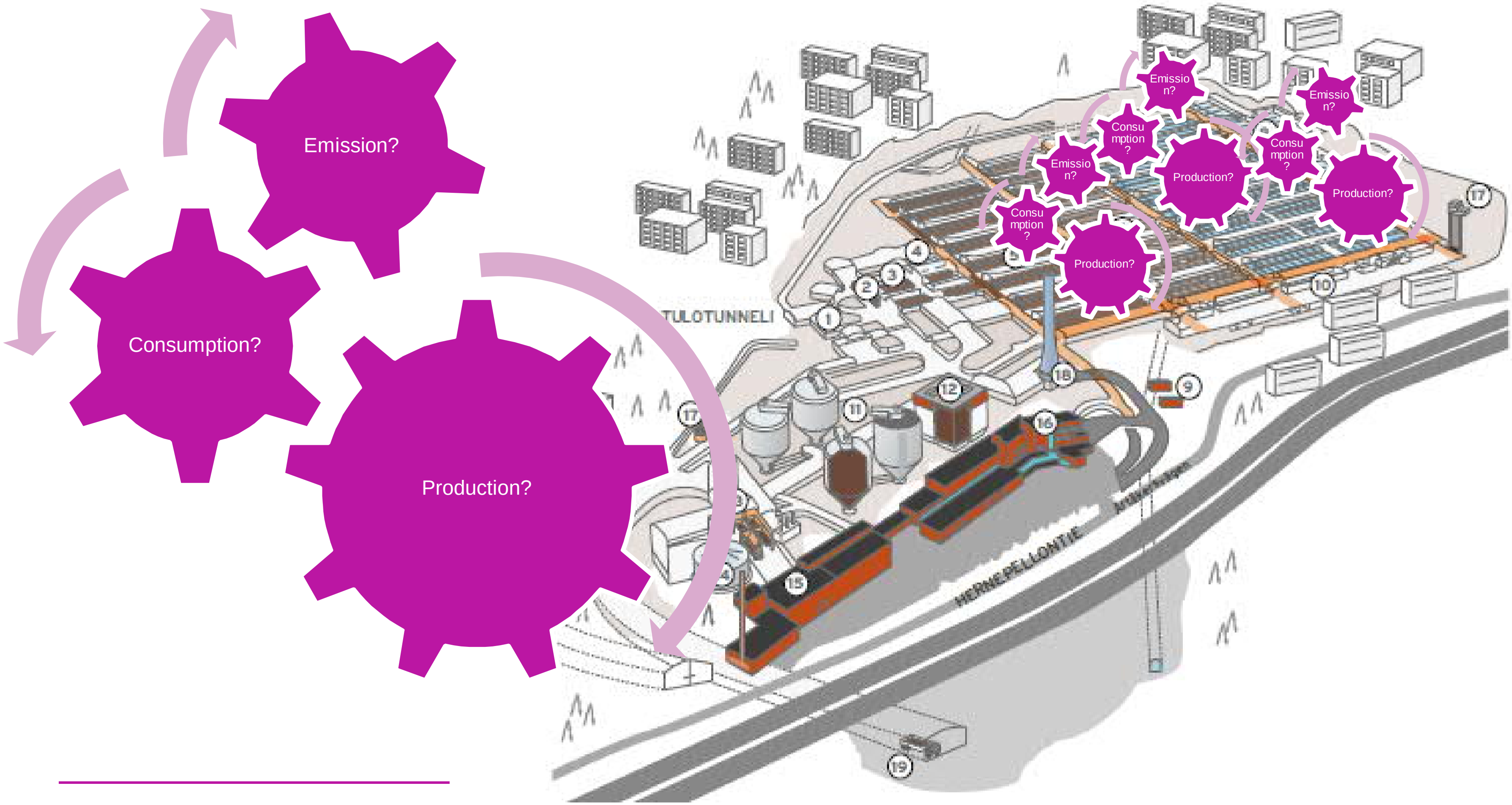


Production of N_2O in the wastewater treatment

Source: Water solutions, 2016



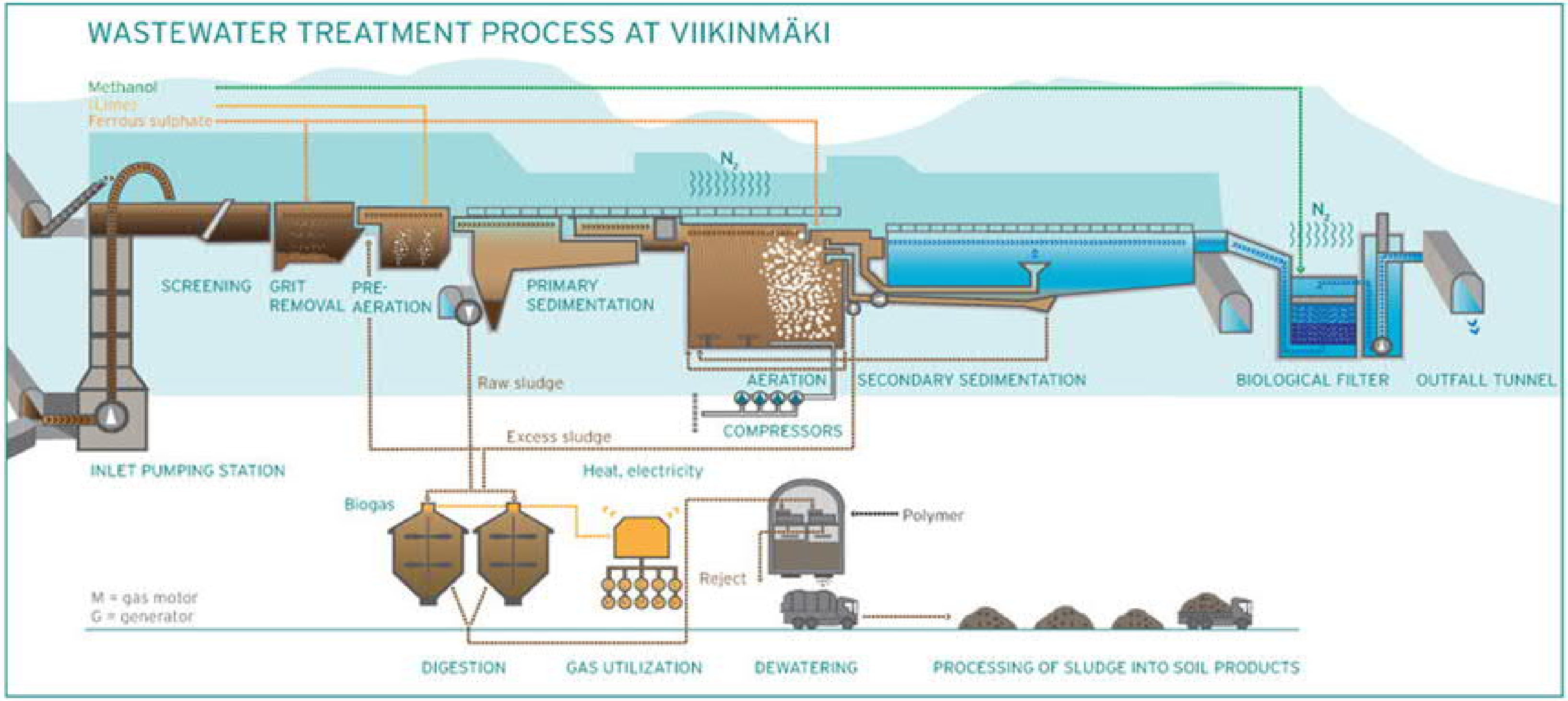
N$_2$O emission is a complicated dynamic process



Viikinmäki WWTP

The Viikinmäki WWTP has a unique setting for studying the production and emissions of N_2O

Long history in N_2O related research with Aalto



Viikinmäki WWTP in Helsinki

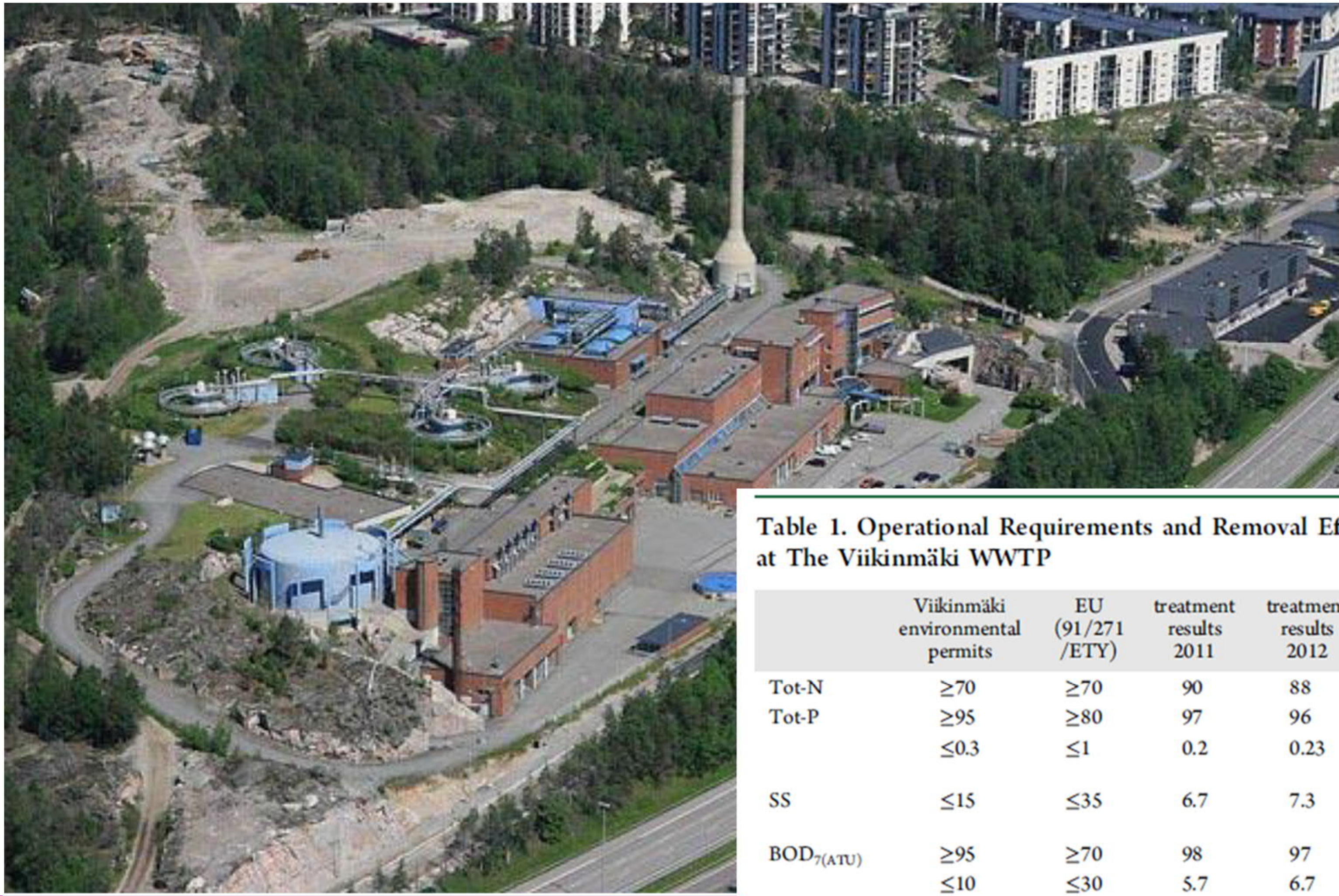
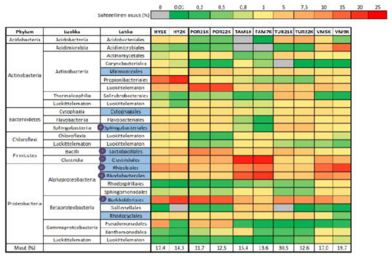


Table 1. Operational Requirements and Removal Efficiency at The Viikinmäki WWTP

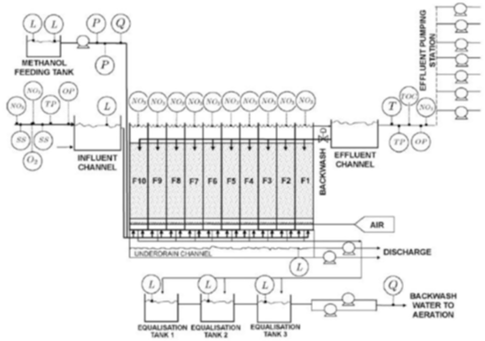
	Viikinmäki environmental permits	EU (91/271 /ETY)	treatment results 2011	treatment results 2012	
Tot-N	≥70	≥70	90	88	%
Tot-P	≥95	≥80	97	96	%
	≤0.3	≤1	0.2	0.23	mg l^{-1}
SS	≤15	≤35	6.7	7.3	mg l^{-1}
$BOD_{7(ATU)}$	≥95	≥70	98	97	%
	≤10	≤30	5.7	6.7	mg l^{-1}
COD_{Cr}	≥80	≥75	92	91	%
	≤75	≤125	40	45	mg l^{-1}

Our N_2O project timeline in Viikinmäki WWTP

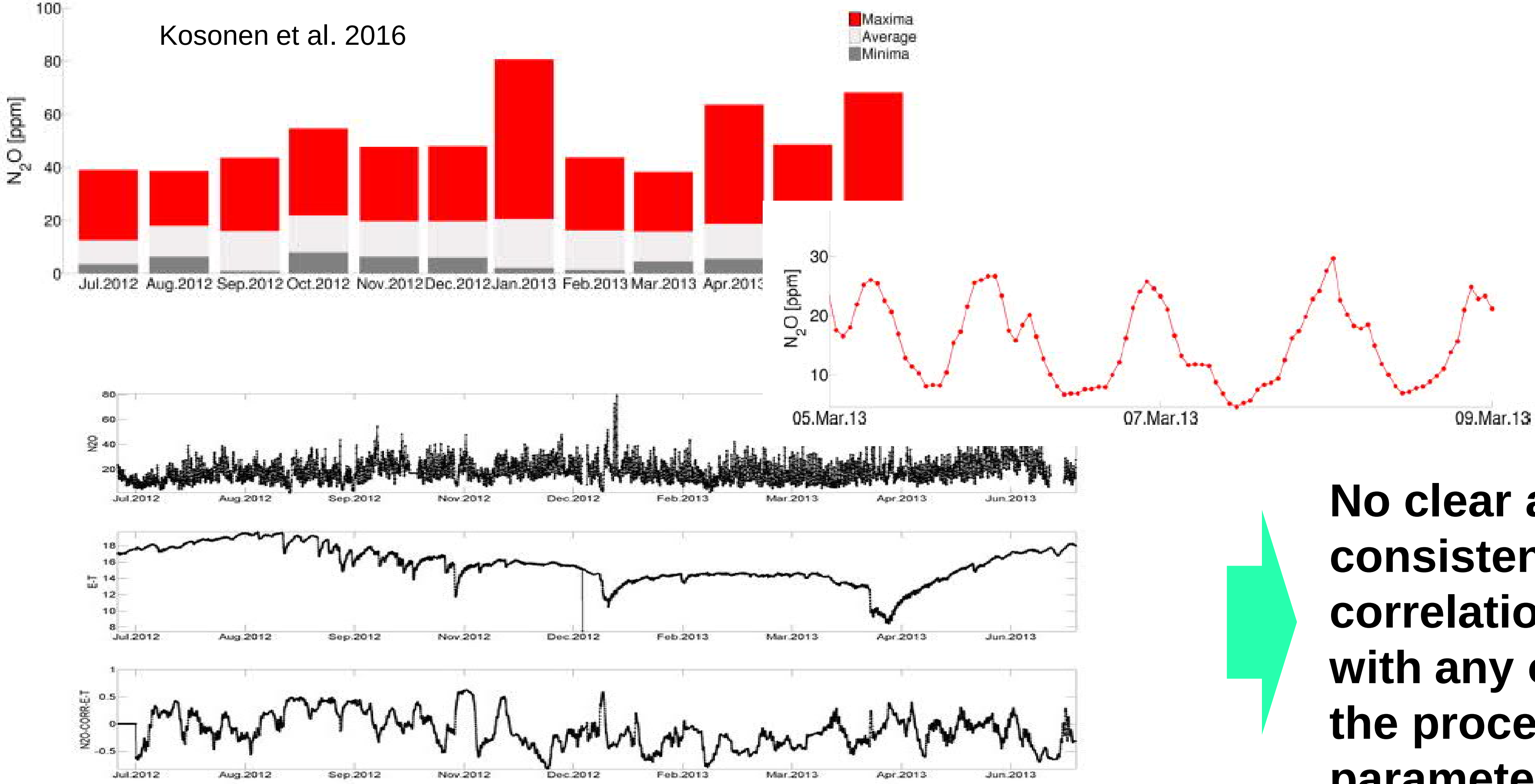
2010	2012	2013	2014	2015	2016	2017
Local measurements with a hood including secondary clarifiers	On-line emission measurement started from the exhaust air pipe	Local measurements from the post-DN-filters	N_2O modelling of the biological process	Comprehensive microbial population studies	Data analysis of the long-term data	



Unisense Environment (2016)



Seasonal and diurnal variation of emissions



No clear and consistent correlation with any of the process parameters

N_2O –modelling at the Viikinmäki WWTP

N_2O model implemented in the existing ASM3-based biological model using GPS-X

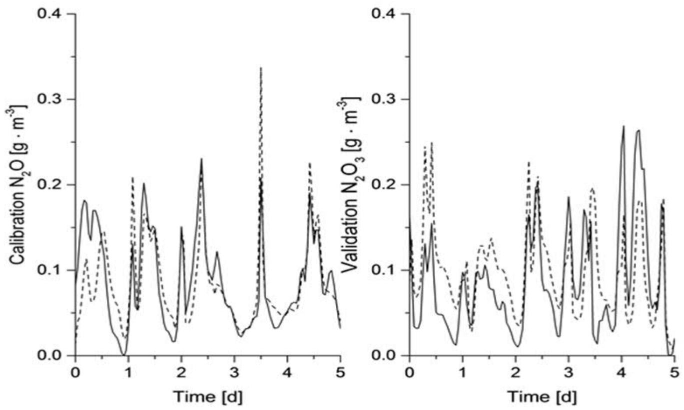
The model includes NH_2OH oxidation pathway (Ni et al., 2013) and heterotrophic denitrification (Hiatt and Grady, 2008)

Calculations for stripping of N_2O included

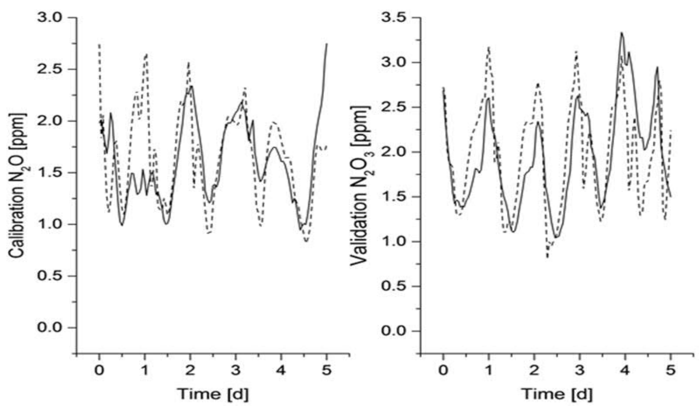
The performance in predicting the liquid phase concentrations and the plant-wide gaseous emissions was tested

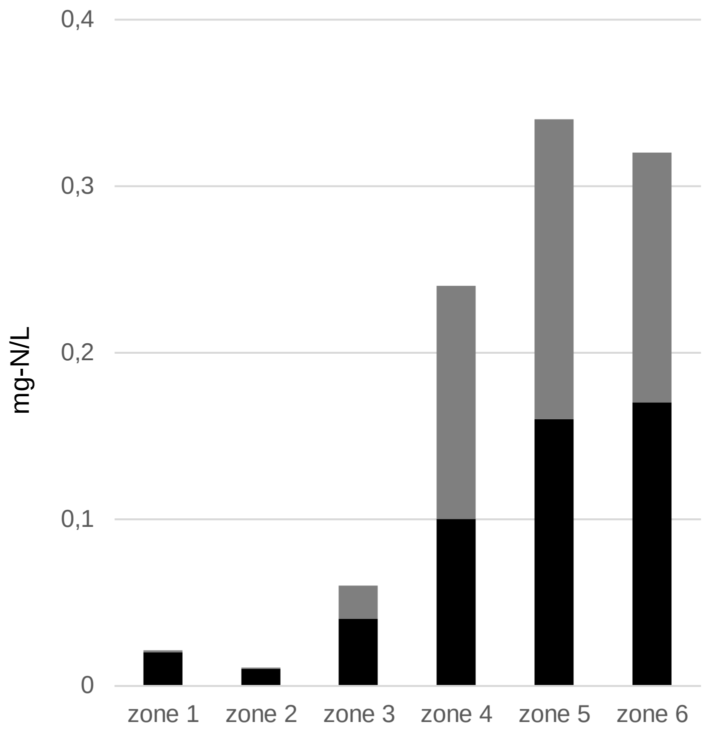
Modelling of N_2O production and emissions

Liquid phase N_2O production in the first aerated zone



Gaseous N_2O emissions





Aeration basin profile of N2O production, comsumption and emission

Testing scenarios for N_2O mitigation

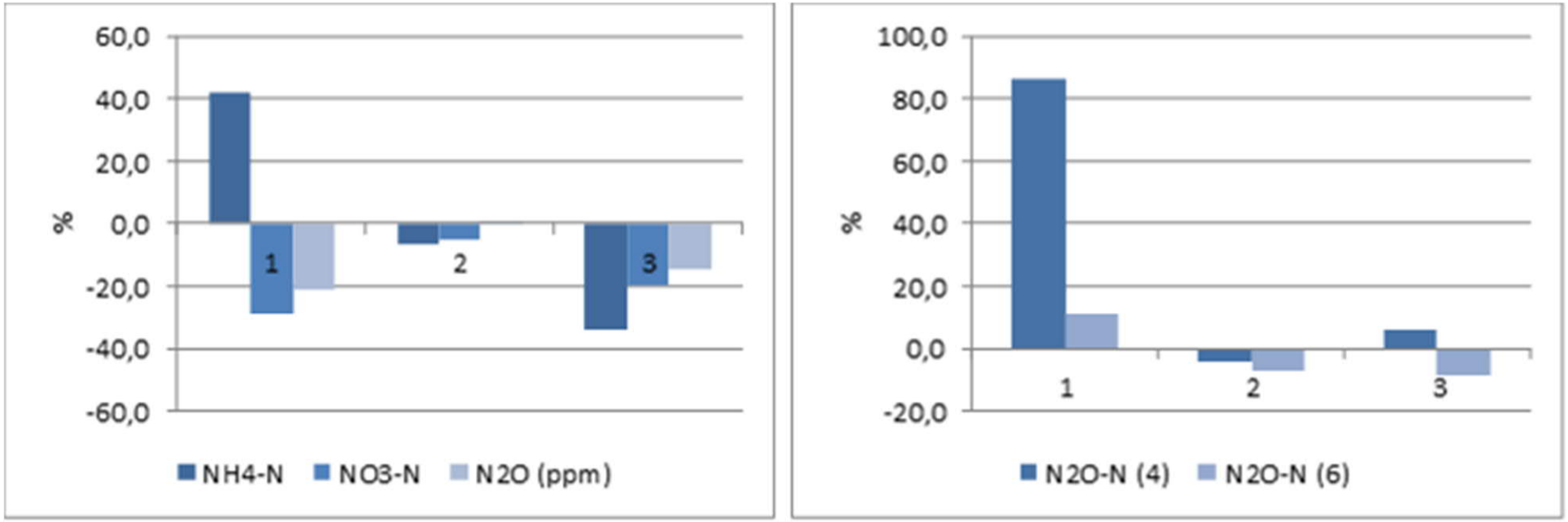
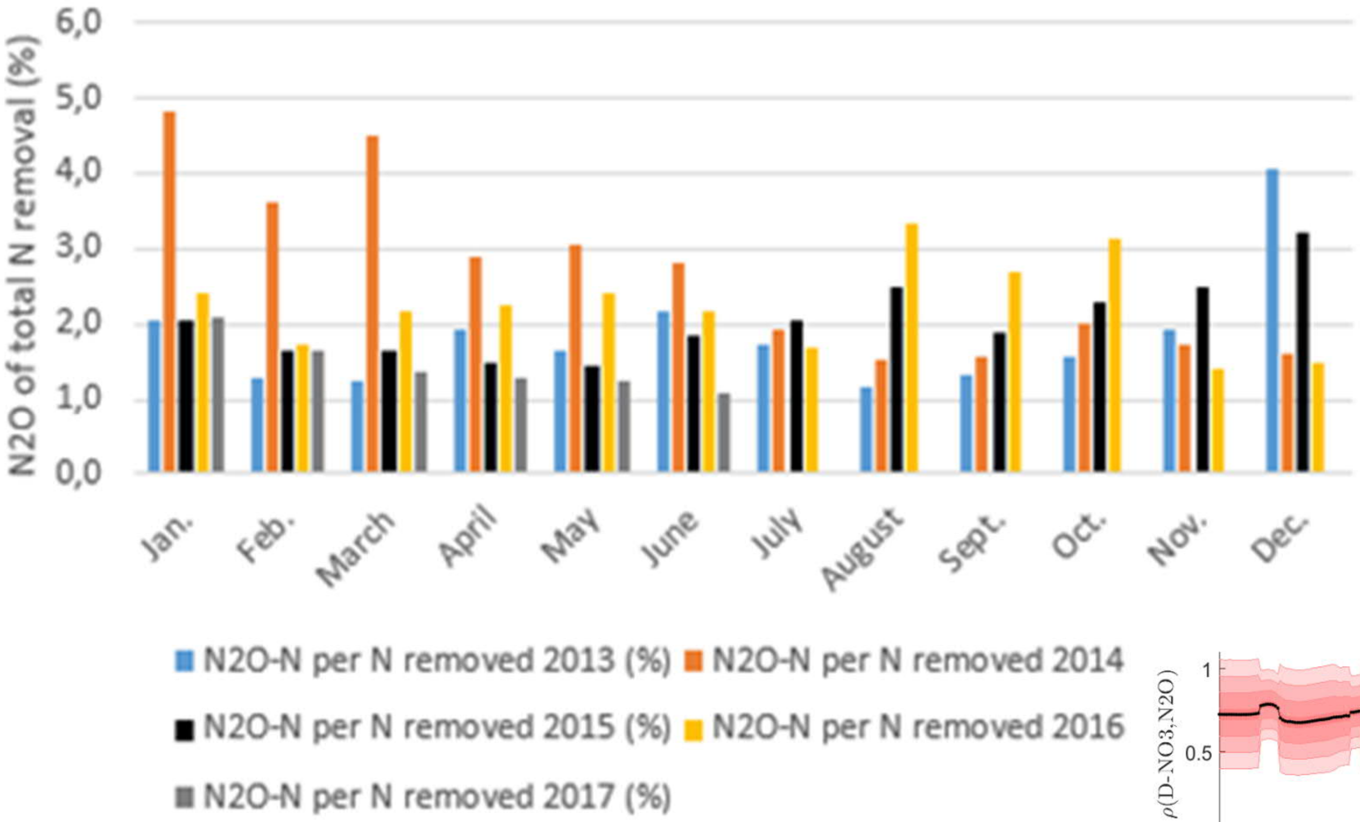
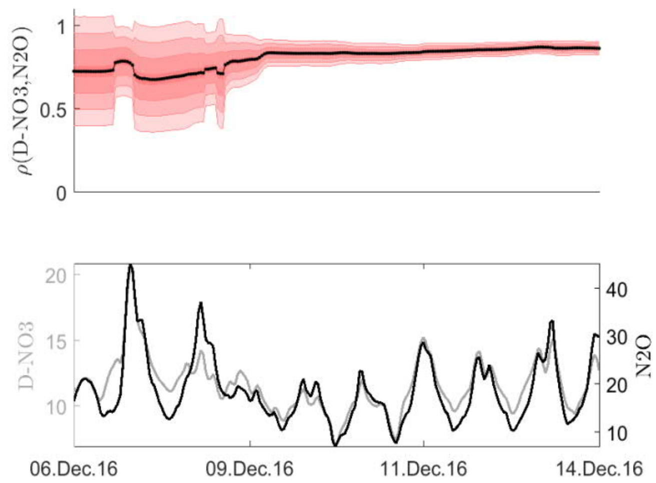


Figure 1 The modelled values of NH4-N and NO3-N in the aeration effluent (mgN/L) and N2O emissions (ppm) in the exhaust air channel on the left and the modelled values of the liquid phase N2O (mgN/L) in the Zones 4 and 6 in each scenarios 1-3 on the right

Scenario 1: The DO set point was set at 2.0 mgO_2/L
Scenario 2: The DO set point based on ammonium load
Scenario 3: The influent nitrogen load was reduced with 10 %

Long-term emissions





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Reflections and lessons learned for emission mitigation strategy

- **Gaseous phase monitoring with FT-IR on-line analyzer gives reliable and stable data**
- **Clark-type micro sensor for liquid phase monitoring is more challenging in real conditions**
- **Tested biological two-pathway model seems to be a fairly useful tool for fine-tuning the process control**
- **Potential process improvements:**
  - Unnecessary aeration should be avoided
  - Denitrifying process parts as a N_2O sink should be used better
  - Separate treatment for digested sludge reject water would decrease emissions in the main process

Identified research challenges

- In Viikinmäki WWTP:

- Find hints of influencing process factors from multivariate analysis of the long-term monitoring
- In order to fully validate the model, expansion of the existing N_2O model to include secondary settling and post-denitrifying filters needed
- The effect of the nitrifying population to be clarified
- The effect of the planned side-stream Anitamox to be clarified

- **In general:**
  - From time to time N2O emissions seem to be decoupled from the nitrogen removal

    → *biological model is not sufficient - development on the basis of data analysis*
  - Improved stripping model needed

    → K_La(N2O) dynamics in real wastewater