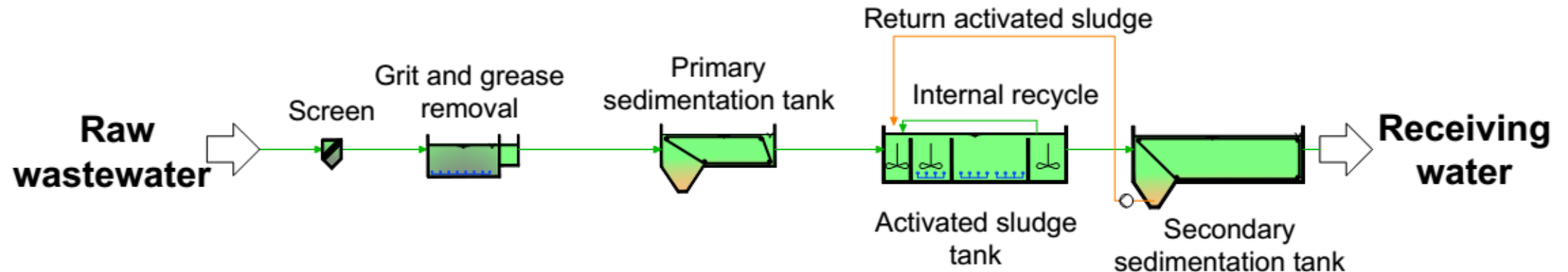


Introduction to Applied wastewater engineering

Michael Jon MATTLE

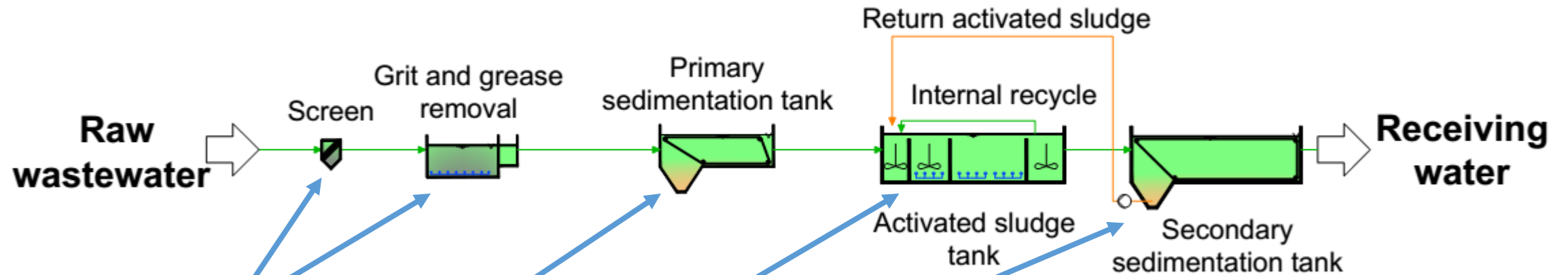


Content of this lecture

- a classical wastewater treatment plant
 - short overview of processes occurring in wastewater treatment plants
- legislation
- how do we currently treat our wastewater?
- Outlook on coming legislation
- what else is important in wastewater treatment plants?
- content of the course
 - lectures
 - exercises
 - field visits
- flow and loading rates
- abbreviations used in this course
- literature

A classical wastewater treatment plant (WWTP)

- what have you learnt so far about wastewater treatment?

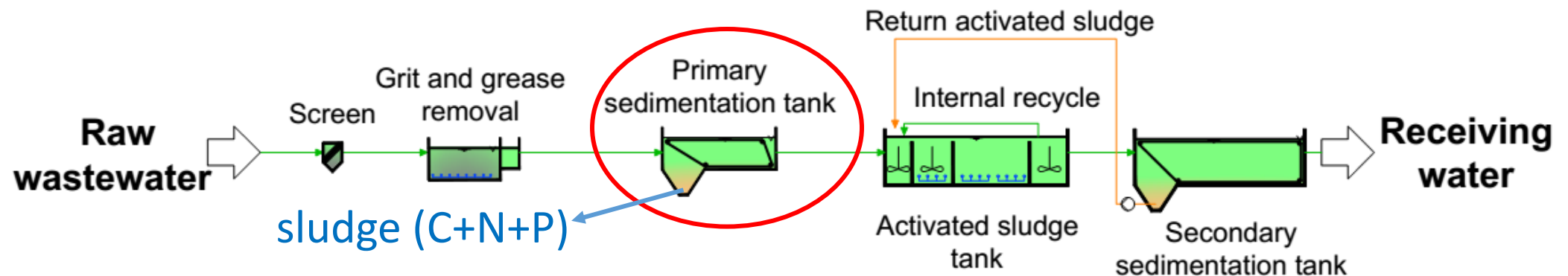


- pre-treatment
- primary clarifier
- biological treatment
- secondary clarifier

A classical wastewater treatment plant (WWTP)

primary clarifier

- removal of particles by sedimentation
- removal of substantial fraction of total suspended solids (TSS): $\geq 50\%$
 - removal of chemical oxygen demand (COD): $\frac{1}{4} - \frac{1}{3}$
 - removal of biological oxygen demand (BOD): $\frac{1}{4} - \frac{1}{3}$
 - little removal of total Kjeldahl nitrogen (TKN-N): about 10 %
 - little removal of total phosphorous (P_{tot}): about 10 %



A classical wastewater treatment plant (WWTP)

What is the effect of primary clarification on next treatment steps?

- A) increased sludge age
- B) increased denitrification
- C) reduced energy consumption
- D) improved secondary clarification

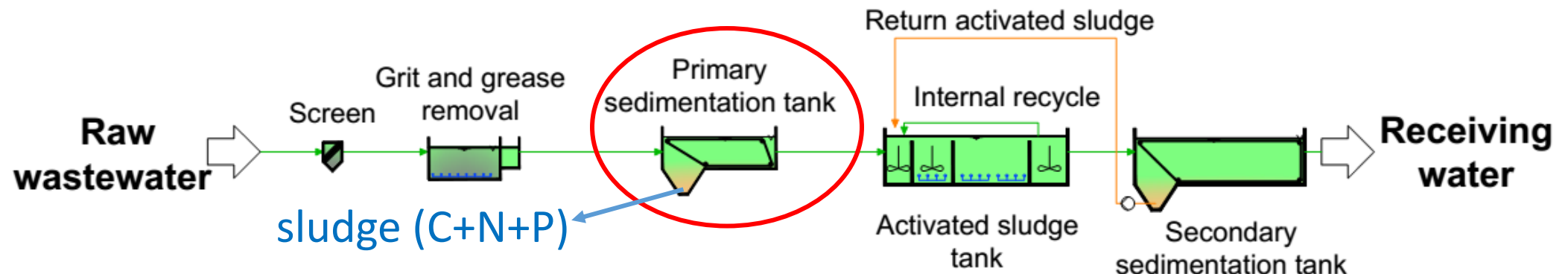
<https://web.speakup.info/room/join/17508>



A classical wastewater treatment plant (WWTP)

primary clarifier

- short residence time as compared to secondary clarifier:
 - $\approx 0.5 - 2.0$ hours at maximal dry-weather flow
- reduced loads (TSS, COD, BOD) for biological treatment
 - reduced size of biological treatment
 - reduced oxygen demand of biological treatment (less energy required)
- “additional” treatment to biological treatment
 - renders treatment train slightly more complex



A classical wastewater treatment plant (WWTP)

What do bacteria do in an aerated tank?

- A) degrade organic pollution
- B) denitrify
- C) consume CO₂
- D) oxidize ammonium (if sludge age is sufficient)

<https://web.speakup.info/room/join/17508>



A classical wastewater treatment plant (WWTP)

biological treatment (activated sludge):

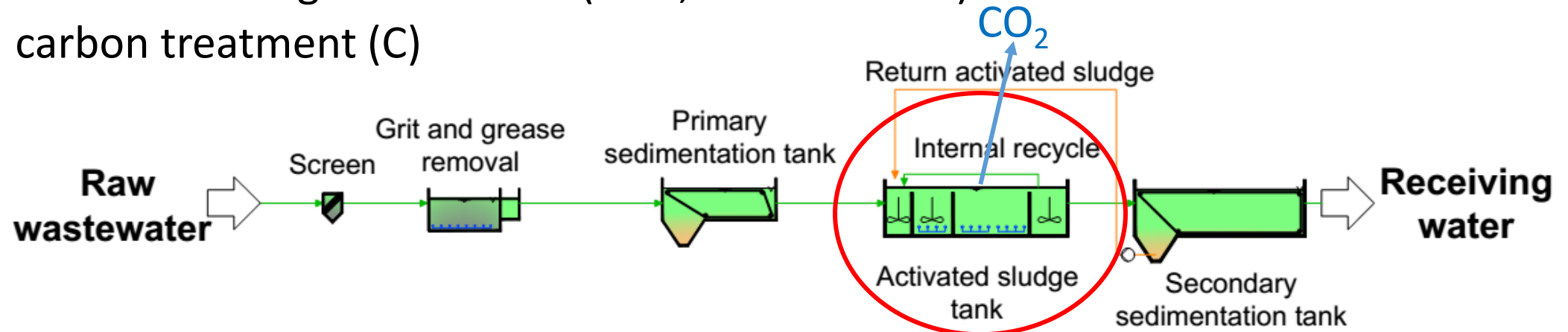
➔ treated in detail in first part of water and wastewater treatment course

- aerated sludge age: $\frac{V_{\text{aerated tank}} \times c_{\text{sludge}}}{\text{Activated sludge production}}$

- with low aerated sludge age (bacteria remain 4 – 5 days in aerated biological tank and temperatures below $\approx 15\text{ }^{\circ}\text{C}$)

➔ oxidation of organic material (COD, BOD removal)

- carbon treatment (C)



A classical wastewater treatment plant (WWTP)

biological treatment (activated sludge)

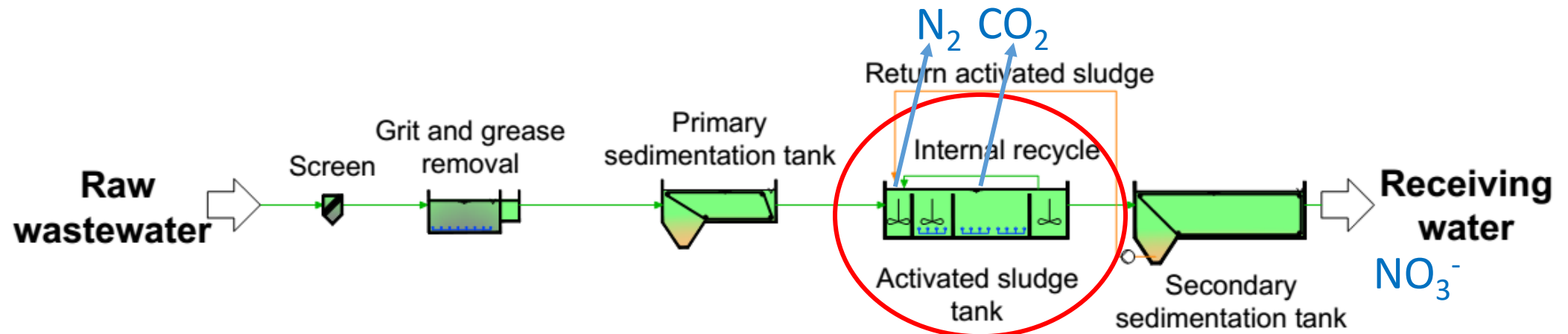
- with increased aerated sludge age ($\geq 8-10$ days in temperate climate)

- oxidation of organic material

- nitrifying bacteria can accumulate in sludge: oxidation of ammonia ($\text{NH}_4^+ \rightarrow \text{NO}_3^-$)

- denitrification possible (anoxic tank + carbon source required): $\text{NO}_3^- \rightarrow \text{N}_2$

 carbon and nitrogen treatment (C+N)

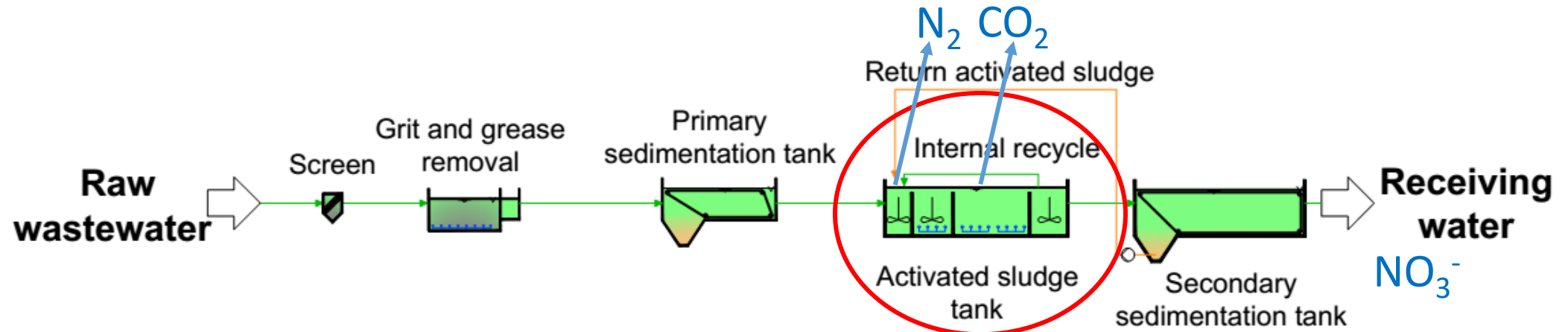


A classical wastewater treatment plant (WWTP)

biological treatment (activated sludge)

- with very high aerated sludge age (≥ 20 days)
 - oxidation of organic material
 - nitrifying bacteria can accumulate in sludge: oxidation of ammonia ($\text{NH}_4^+ \rightarrow \text{NO}_3^-$)
 - denitrification possible (anoxic tank + carbon source required): $\text{NO}_3^- \rightarrow \text{N}_2$
 - oxidation of sludge = sludge stabilisation

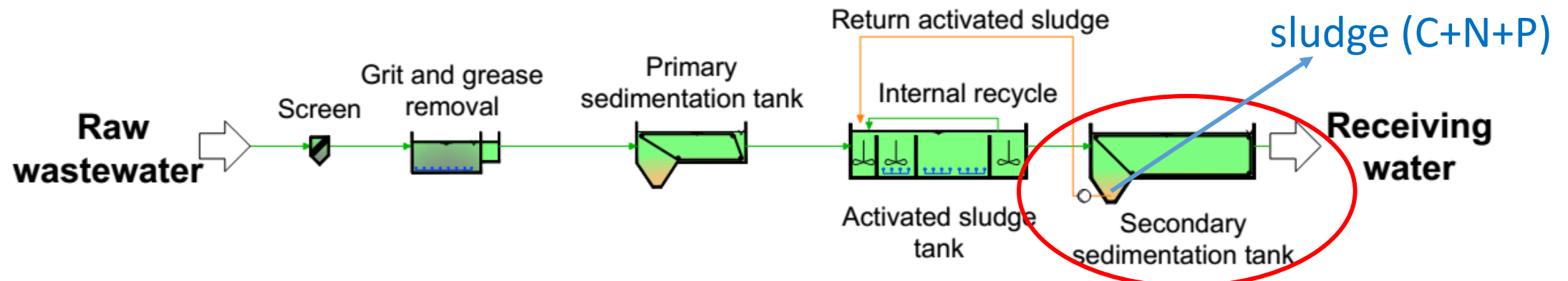
→ carbon and nitrogen treatment (C+N) + sludge stabilisation



A classical wastewater treatment plant (WWTP)

secondary clarifier

- separation of activated sludge (bacteria) from treated water
 - removal of TSS (bacteria) to obtain transparent treated water
 - thickening of activated sludge
 - sludge extraction
- sludge recirculation
 - returns biological active sludge to biological tank
 - increases inflow of biological tank by roughly 100 %!!



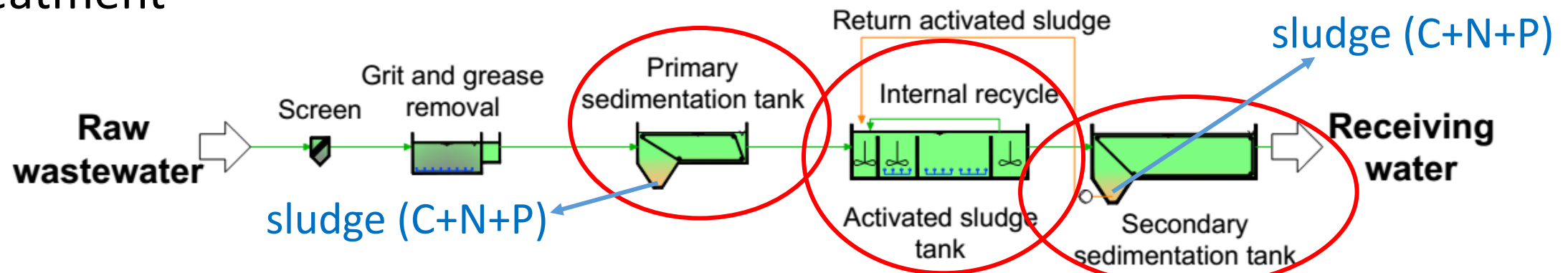
A classical wastewater treatment plant (WWTP)

phosphorous removal

- addition of coagulants (either Fe(III) or Al(III))
 - precipitation of phosphorous (FePO_4 or AlPO_4)
 - coagulants can be added into biological tank or to wastewater entering primary sedimentation tank
 - precipitated phosphorous is either removed in secondary or primary sedimentation tank

→ carbon, nitrogen and phosphorous removal (C+N+P)

- bio-P removal: treated in detail in first part of water and wastewater treatment



Current legislation (excluding micropollutants)

- In which treatment steps are these defined parameters (Annex 3 of Waters Protection Ordinance) removed?
 - total suspended solids
 - chemical oxygen demand (COD)
 - dissolved organic carbon (DOC)
 - ammonium
 - nitrite
 - phosphorous

2 General requirements

No.	Parameter	Requirements
1	Total suspended solids	<p>For waste water from plants of less than 10 000 PE the following requirements apply:</p> <ul style="list-style-type: none"> – discharge concentration: 20 mg/l <p>For waste water from plants from 10 000 PE the following applies:</p> <ul style="list-style-type: none"> – discharge concentration: 15 mg/l
2	Chemical oxygen demand (COD)	<p>For waste water from plants of less than 10 000 PE the following requirements apply:</p> <ul style="list-style-type: none"> – discharge concentration: 60 mg/l O₂ and – removal efficiency, with respect to raw waste water: 80% <p>For waste water from plants of 10.000 PE or over the following requirements apply:</p> <ul style="list-style-type: none"> – discharge concentration: 45 mg/l O₂ and – removal efficiency, with respect to raw waste water: 85%
3	Dissolved organic carbon (DOC)	<p>For waste water from plants of 2000 PE or over the following requirements apply:</p> <ul style="list-style-type: none"> – discharge concentration: 10 mg/l and – removal efficiency: 85%, expressed as $100 \cdot \left(1 - \frac{\text{mg DOC in purified waste water}}{\text{mg total organic carbon in raw waste water}} \right)$ <p>If the value is not complied with, the authorities shall assess the substances, determine their origin and if necessary specify the required procedures in accordance with Annexes 3.2 and 3.3.</p>

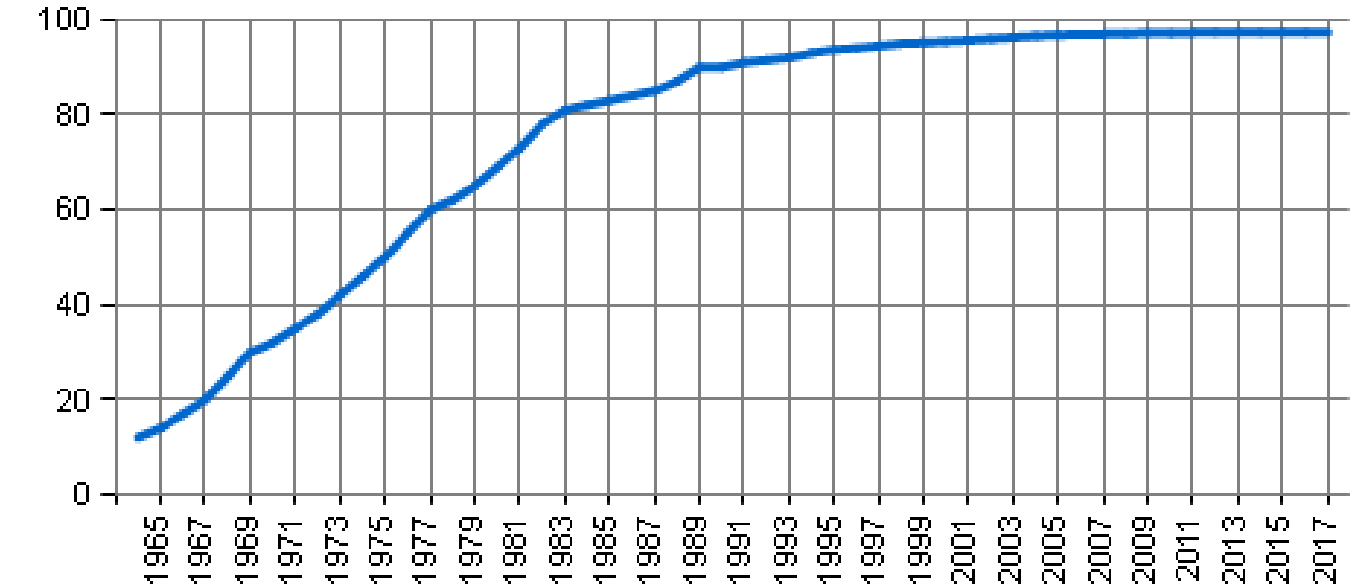
Current legislation (excluding micropollutants)

- Parameter that is not yet defined:
 - Total nitrogen

No.	Parameter	Requirements
2	Total nitrogen	<p>In plants for which no discharge concentration and no removal efficiency for total nitrogen is specified, must be operated in such a way that during waste water purification and sludge treatment as much nitrogen as possible is eliminated. All structural modifications which are possible at no great cost must be undertaken; this applies particularly to plants that already carry out nitrification.</p> <p>Prior to 28 February 2002, cantons in the catchment area of the Rhine shall work out a plan on how to reduce discharges of nitrogen by 2600 tonnes compared to 1995 with effect from the year 2005 onwards. Plants that are earmarked in this plan for nitrogen elimination must be operational by 2005 at the latest.</p>

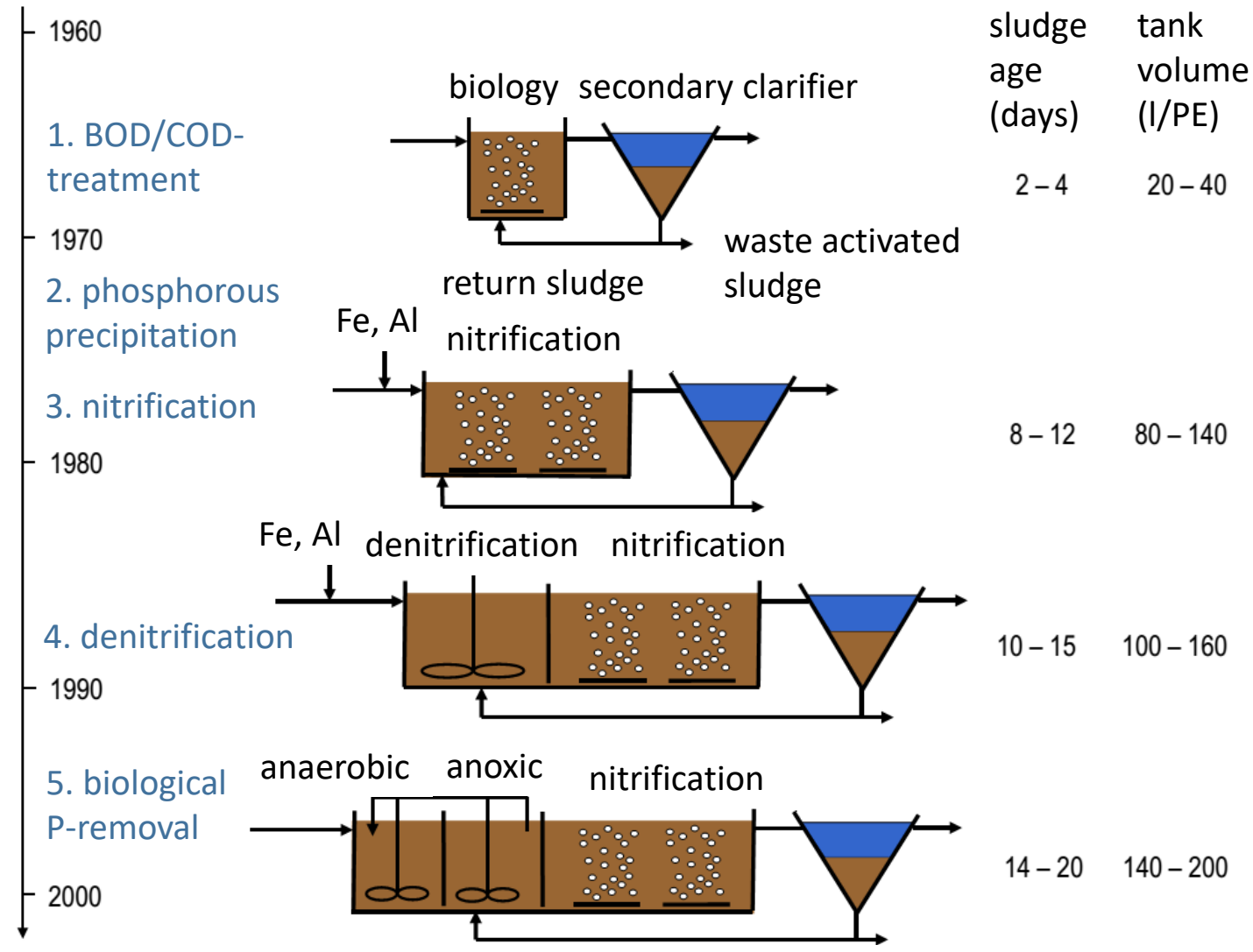
How do we currently treat wastewater in Switzerland?

- since the mid-twentieth century, the Swiss population connected to a WWTP has constantly increased
- today nearly a 100 % of the population is connected to a WWTP
- large parts of the world are still lacking such infrastructure



— Swiss population in % connected to a central wastewater treatment plant (WWTP), Federal Office for the Environment (FOEN)

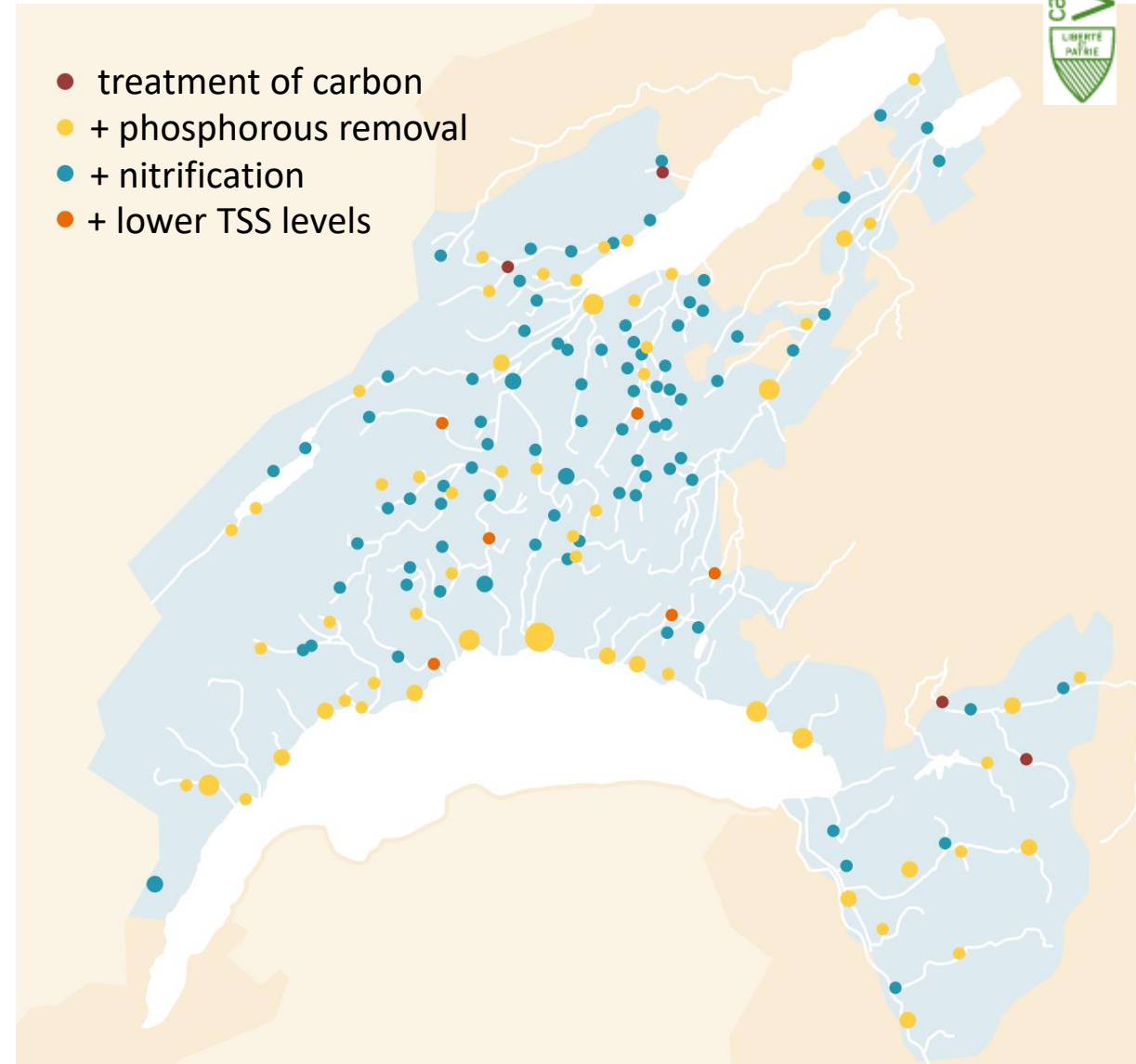
How do we currently treat wastewater in Switzerland?



- 40 – 50 billions of Swiss Francs were invested to built the current infrastructure:
 - sewer system 40'000 – 50'000 km long (about once around the world!)
 - ≈ 800 wastewater treatment plants
- current replacement value: 80 -100 billions of Swiss Francs

Wastewater treatment in Canton of Vaud

- high number of WWTP (153 in 2020) in Canton of Vaud (nearly 20 % of the Swiss WWTP)
 - this number is reducing (construction of larger regional WWTP)
- most larger WWTP of Canton of Vaud 'only' treat carbon and phosphorous
- smaller WWTP treat carbon, phosphorous and ammonium (nitrification)



Wastewater treatment in Canton of Geneva



- wastewater treatment comes at a cost
- a small canton like Geneva (2020) has:
 - a sewer system of 1'200 km
 - 5 wastewater treatment plants
 - 112 collaborators
 - 34 pumping stations
 - 7'788000 m³ biogas produced
 - and is collecting 2'272 litres of wastewater every second

5

STEP

7 602 964

M³ DE BIOGAZ PRODUIT

1200

KM DE RÉSEAU

34

STATIONS DE POMPAGE

72

MILLIONS DE M³ D'EAUX USÉES
RÉCEPTIONNÉES, SOIT L'ÉQUIVALENT DE
25 000 PISCINES OLYMPIQUES

2272

LITRES D'EAUX USÉES COLLECTÉES DANS
LE RÉSEAU CHAQUE SECONDE

112

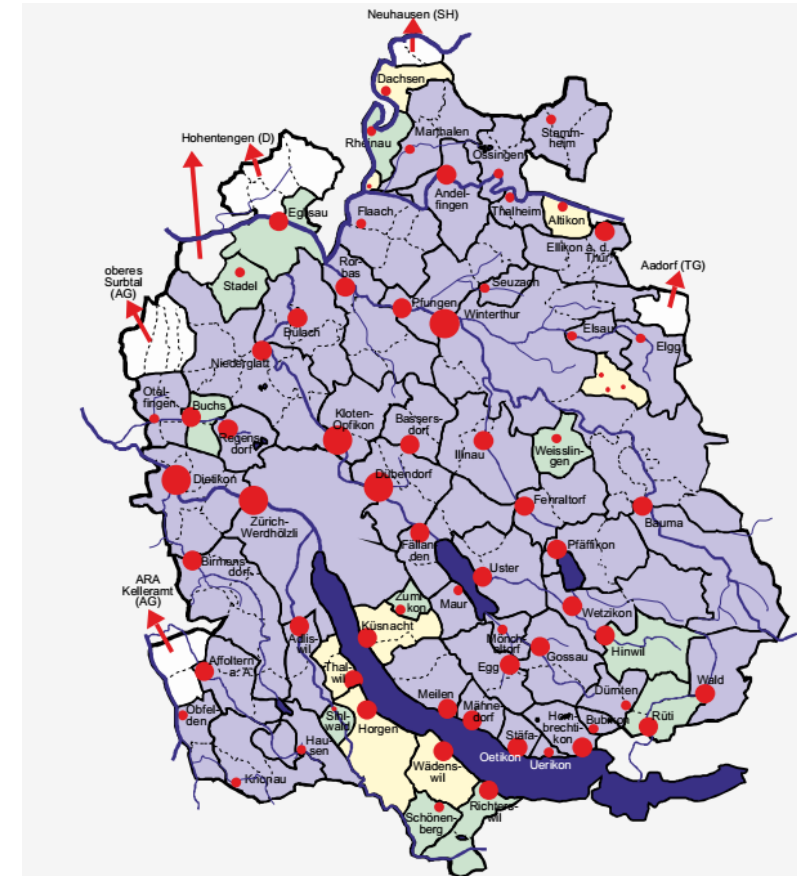
COLLABORATEURS·TRICES



Wastewater treatment in Canton of Zurich

state in 2019

- most WWTP in the Swiss German part of Switzerland (receiving water: Rhine) have been designed to nitrify
- the Canton of Zurich has many large wastewater treatment plants (> 50'000 PE)
- most WWTP nitrify and denitrify
- a small fraction of WWTP only nitrify during the warmer period of the year
- a small fraction of wastewater is treated in other cantons (Argovie, Thurgovie and Schaffhouse) or even in abroad (Germany)



- < 1'000 PE
- 1'000 – 10'000 PE
- 10'0000 – 50'000 PE
- > 50'000 PE

- nitrification only during warmer period
- nitrification during entire year
- nitrification and partial denitrification
- catchment basin

Outlook on coming legislation

- both federal chambers accepted motion 20.4261 that demands measures to reduce total nitrogen loads from WWTPs
- the Federal Office for the Environment is currently elaborating a modification of the Waters Protection Ordinance.
 - a modified ordinance may come into force in 2029

20.4261 MOTION

Réduction des apports d'azote provenant des stations d'épuration des eaux usées

Submitted by: [COMMISSION DE L'ÉCONOMIE ET DES REDEVANCES CN](#)

Rapporteur: [REGAZZI FABIO](#), [SCHMID MARTIN](#), [WALTI BEAT](#)

Submission date: 13/10/2020

Submitted: Conseil national

State of deliberations: Transmis au Conseil fédéral

 COLLAPSE ALL

 SUBMITTED TEXT

Le Conseil fédéral est chargé de s'attaquer rapidement au problème des apports, dans les eaux, d'azote provenant des stations d'épuration des eaux usées (STEP) et de prendre des mesures pour les réduire.

 GROUNDS

Avec le rendement actuel des STEP, des quantités massives d'azote sont déversées dans les eaux et, indirectement, dans les eaux souterraines.

En Suisse, 14 g d'azote sont libérés par jour et par personne (cf. Pöpel, 1993 ; Guyer & Larson, 1996 ; Siegrist & Boller 1996). Notre pays comptant 8,6 millions d'habitants, cela signifie 43 946 tonnes d'azote total par an. D'après les projections du rapport de l'OFEV intitulé " Flux d'azote en Suisse en 2020 ", qui date de 2013, la performance d'élimination de l'azote des STEP se monte à 47 % en 2020 : ainsi, les STEP libèrent 23 292 tonnes d'azote dans les eaux et les airs.

Concernant les nitrates, 11 g sont libérés par jour et par personne (rapport précité de l'OFEV) : considérant une performance d'élimination de l'azote de 47 %, cela correspond à des pertes de nitrates de 18 300 tonnes par an par le biais des STEP. Selon le rapport agricole, 51 493 tonnes de nitrates sont déversées annuellement dans les eaux suisses, dont 32 208 tonnes proviennent de l'agriculture. Avec 18 300 tonnes, les STEP seraient ainsi responsables de presque 36 % de tous les apports en nitrates.

Outlook on new European legislation



Official Journal
of the European Union

EN
L series

2024/3019

12.12.2024

DIRECTIVE (EU) 2024/3019 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 27 November 2024

concerning urban wastewater treatment

(recast)

(Text with EEA relevance)

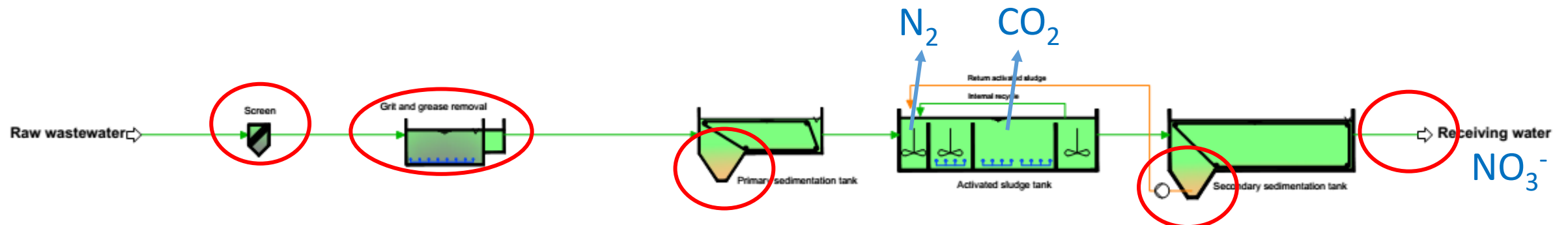
- revised Urban Wastewater Treatment Directive (accepted in November 2024:

- P_{tot}: 0.5 mg/L and 90 % (yearly average) for 150'000 PE and above
- N_{tot}: 8 mg/L and 80 % (yearly average) for 150'000 PE and above
- energy neutrality for all WWTP > 10'000 PE

 it will have a huge impact on wastewater treatment in Europe

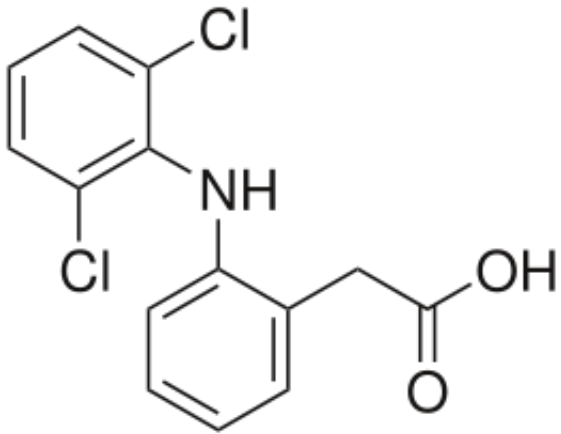
A classical wastewater treatment plant

- if the treated effluent has acceptable levels in COD, BOD, TSS, ammonia and P_{tot} , what else is important in a wastewater treatment plant?
- how to handle primary, secondary sludge?
- what to do with screenings and grit?
- how to manage bad odours generated in wastewater treatment plants?
- how can we further increase the effluent water quality?



Content of 'Applied wastewater treatment'

- organic micropollutant treatment



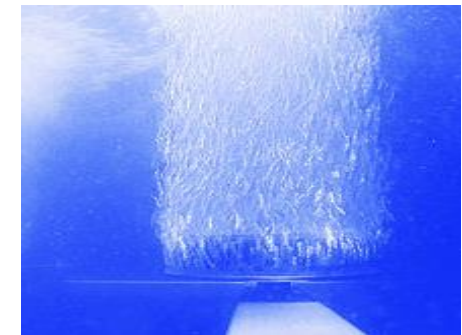
Content of 'Applied wastewater treatment'

- organic micropollutant treatment



10 g

≈ surface of



Content of 'Applied wastewater treatment'

- air emission control



Field visits (not yet confirmed)

- WWTP VOG (powered activated carbon treatment)
- WWTP Penthaz (fluidised activated carbon treatment)



Exercise sessions

- questions that an engineer in the field of wastewater treatment may be asked to answer
- computations that must be conducted by an engineering company working in the field of wastewater engineering
- One long exercise that shows the interactions in a WWTP

 **Applied** wastewater engineering



Exam dates

- Midterm exam (30 %): October 14th, 2025
- Final exam (70 %): December 9th, 2025
- good for you or would you prefer other dates?
- exam is closed book, why?
 - exercises shall show how you are able to solve problems and not to reproduce/copy what you have already done (engineers should be 'ingénieux')
 - in the real world of engineering, the knowledge you have present in your mind is most helpful (e.g. meetings with clients), secondly you should know where to look up things that you do not know (e.g. water protection ordinance)
 - the objective is not that you learn everything by heart but that you know and understand the topics and are able to give illustrative examples

Loading rates

- statistical analysis (e.g. VSA or DWA) of data from wastewater plants allows to determine the following mass loading rates (= flowrate x concentration):


average mass loading rate (kg/d)

- used to compute **average** yearly energy consumption (e.g. aeration)
- used to compute **average** yearly sludge production

(design) mass loading rate (kg/d): generally determined by the 85th percentile of all mass loading rates

can also be determined as maximum of average-two-weeks mass loading rates

- used to **design** wastewater treatment plants (biological reactors)
- used to **design** sludge treatment train (e.g. sludge thickening, digesters)

 wastewater treatment plant has to be capable to treat loading rates higher than average values

Specific (design) loading rates per population equivalent (PE)

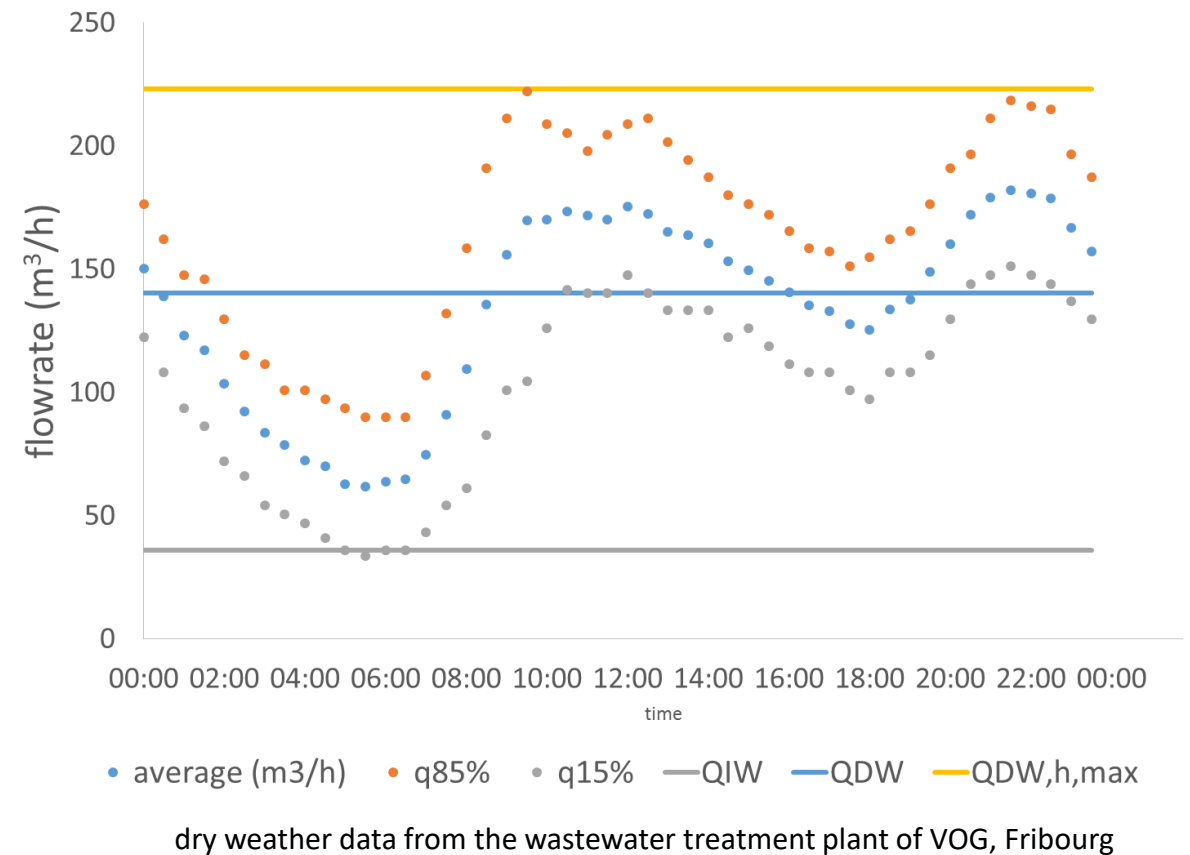
item	specific (design) loading rates (g/PE·d)
COD	120
BOD ₅	60
TSS	70
TKN	11
P _{tot}	1.8

values from DWA (ATV-A 131)

Flow rates

statistical analysis (e.g. VSA or DWA) of data from wastewater plants allows to determine the following flowrates:

- Average daily flow rate
- Q_{DW} (daily dry weather flow rate)
- $Q_{DW,h,max}$ (max. hourly dry weather flow rate)
- $Q_{DW,2h,max}$ (max. two hourly dry weather flow rate)
- Q_{RW} (max. rainy weather flow rate) = maximal flow rate accepted to wastewater treatment plant
- Q_{IW} (infiltration water flow rate)



Abbreviations used in the course

physical characteristics	abbreviation	translation in French
chemical oxygen demand	COD	demande chimique en oxygène (DCO)
biological oxygen demand	BOD	demande biologique en oxygène (DBO)
5-day biological oxygen demand	BOD ₅	DBO ₅
total solids (generally used for sludge characterisation)	TS	matières sèches (MS)
total volatile solids	TVS	matières volatiles sèches (MVS)
total suspended solids (generally used for wastewater characterisation)	TSS	matières en suspension (MES)
volatile suspended solids	VSS	matières volatiles en suspension
total organic carbon	TOC	carbone organique total (COT)
dissolved organic carbon	DOC	carbon organique dissous (COD)
population equivalents	PE	equivalent-habitant (EH)
wastewater treatment plant	WWTP	station d'épuration (STEP)
organic micropollutant	oMP	micropolluant organique

Chemical constituents

chemical name	
ammonia	NH_3
ammonium	NH_4^+
nitrite	NO_2^-
nitrate	NO_3^-
orthophosphate/o-phosphate	PO_4^{3-}
chloride	Cl^-
sulphate	SO_4^{2-}

Definitions/units

name	sign	units (example)
length	L	m
surface	S	m ²
volume	V	m ³
flow rate	q	m ³ /h
load		kg
(daily) mass loading rate (e.g. entry WWTP)		kg/d
massflow rate (e.g . sludge)		kg/d
Overflow rate/hydraulic loading rate		m/h=m ³ /(m ² x h)
filtration rate (sand filters)		m/h=m ³ /(m ² x h)
product dose		mg/L
solids loading rate (e.g. sludge flotation)		kg/(m ² x d)

Literature

most chapters are covered in

- Wastewater Engineering: Treatment and Resource Recovery, Metcalf & Eddy \ Aecom, Fifth Edition **2014**

technical notes on most chapters (for details see the literature summary at the end of each chapter):

- Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (**DWA**)
- most technical notes are only available in German
- some are available with NEBIS

Many thanks for their help in preparing this lecture to

- Manfred Tschui, Michael Thomann, Johanna Obrecht, Brian Pecson, Tanguy Thomas de la Pintièrre, Urs von Gunten and Christof Holliger