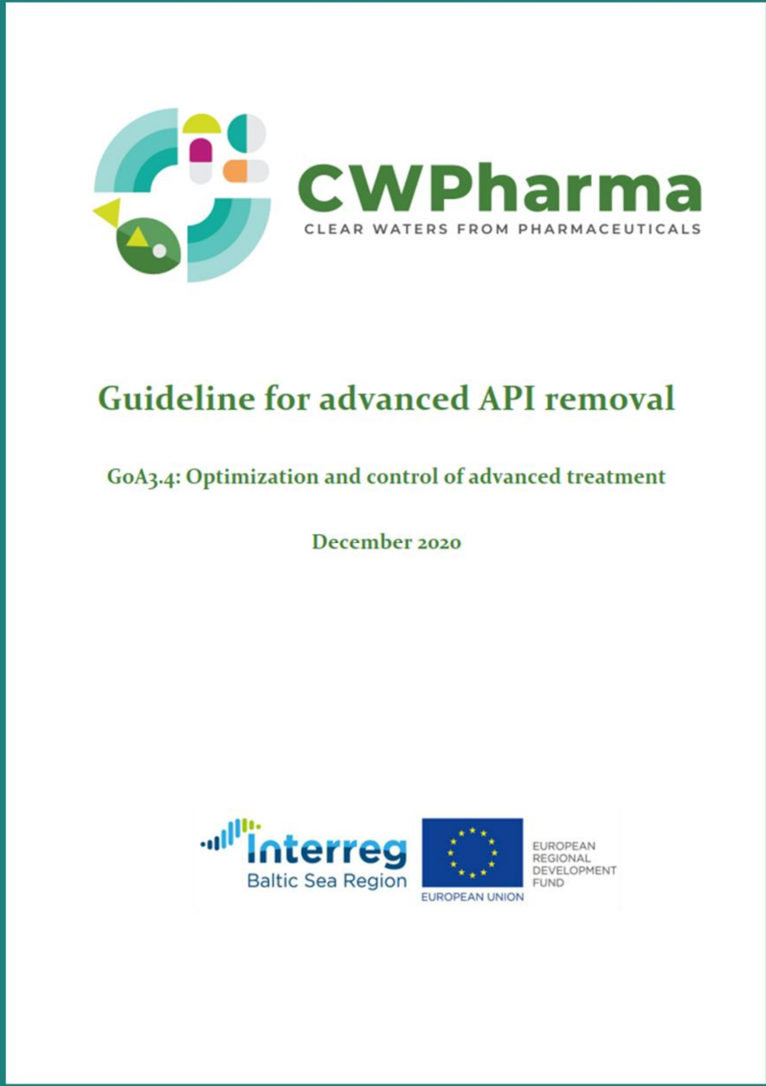
Feasibility study of API removal at the Helsinki Viikinmäki WWTP

GoA 2.2: Applying recommendations for planning of API removal and plant optimization

The CWPharma Guideline for advanced API removal


CWPharma
CLEAR WATERS FROM PHARMACEUTICALS

Guideline for advanced API removal

GoA3.4: Optimization and control of advanced treatment

December 2020

Interreg
Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Contents of the guideline

A compact overview on how to plan, start, and operate AWT technologies for API elimination (39 p.):

1. Basics, process descriptions, relevant water quality parameters, barriers, by-product formation, operational aspects, monitoring, carbon footprint, overview on costs… for
   - Ozonation
   - Powdered activated carbon (PAC)
   - Granular activated carbon (GAC)
   - MBBR
2. Recommendations on implementation of AWT for API removal divided in four modules

The CWPharma Guideline for advanced API removal
Implementation of an API elimination technology

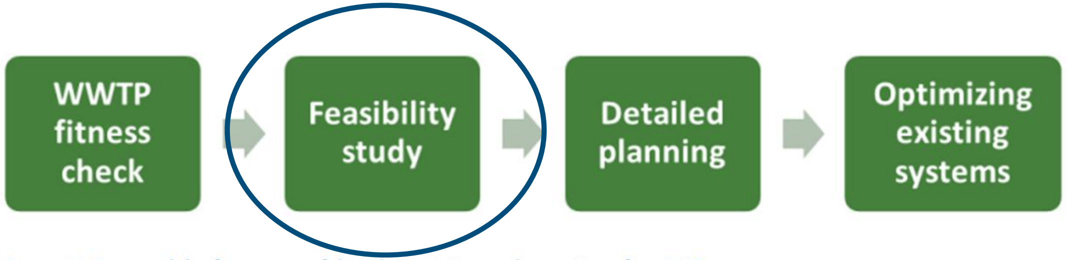


Figure 11: Four modules for a successful implementation and operation of an AWT.

Feasibility study

1. Ambition of the API elimination technology
2. Status of the WWTP
3. API monitoring campaigns
4. State of the art / knowledge of AWT
5. Preliminary design of AWT technology
6. Costs
7. Overall evaluation

1. Ambition of the API elimination technology

- **CWP Guideline:**
  - Ambitions / targets for the API elimination technology
  - A brief summary on the WWTP’s impact on drinking water sources, bathing waters and the ecological status of the receiving water body

1. Ambition of the API elimination technology Viikinmäki WWTP

- The Helsinki Region Environmental Services HSY’s goals are
  - Sea protection and decreasing the API load in the environment
  - Complying with anticipated future requirements
  - (Long effluent pipe to sea, no impact on drinking water sources or bathing waters)

à Preliminary design was based on 80 % reduction as yearly average

- Current challenges for planning API removal at Viikinmäki WWTP:
  - No requirements for API removal – yet (renewal of the Urban WWT directive 91/271/ECC by 2023?)
  - Post treatment for API removal is a significant investment
  - No space at the current treatment plant
  - Large WWTP in mid city – new housing areas being built all around
    à very limited options on where to build
  - Space reservation made in the city underground zoning
    à Will excavations have to be done before houses are built above?

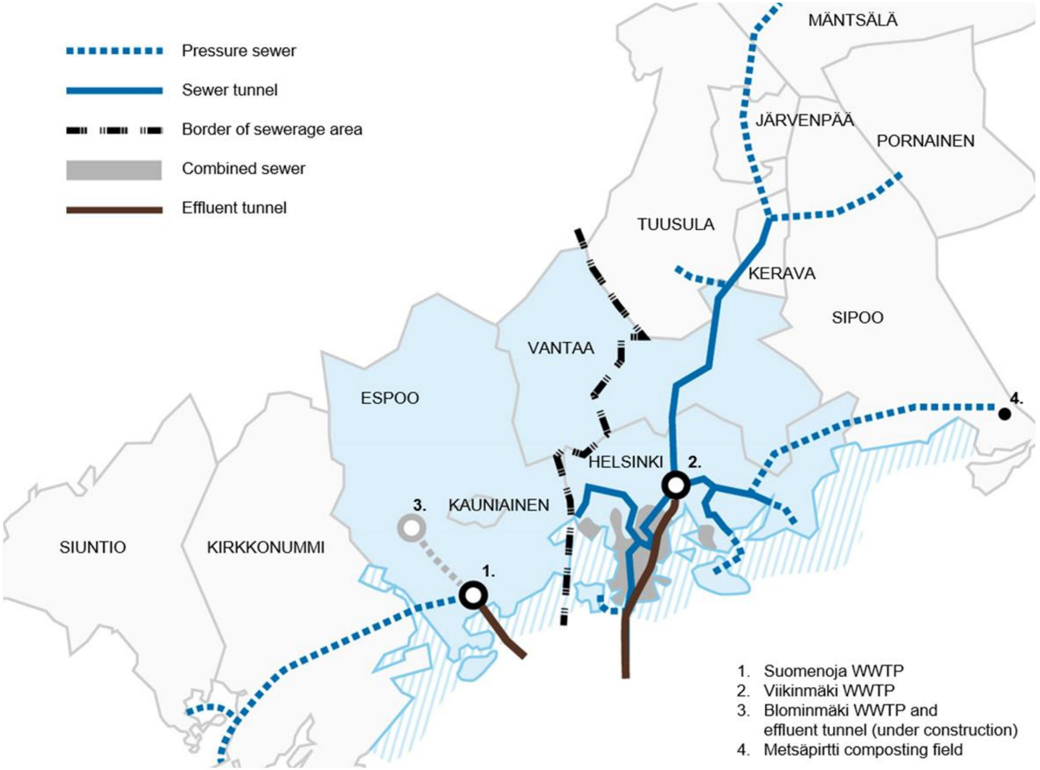
2. Status of the WWTP

- **CWP Guideline:**
  - Catchment area including relevant hotspots (e.g. hospitals)
  - Description of processes and the load and dimensioning of the treatment plant
  - Relevant concentrations (DOC, COD, TSS, NO_2^-, Br^-)

Availability check included in the Fitness check module

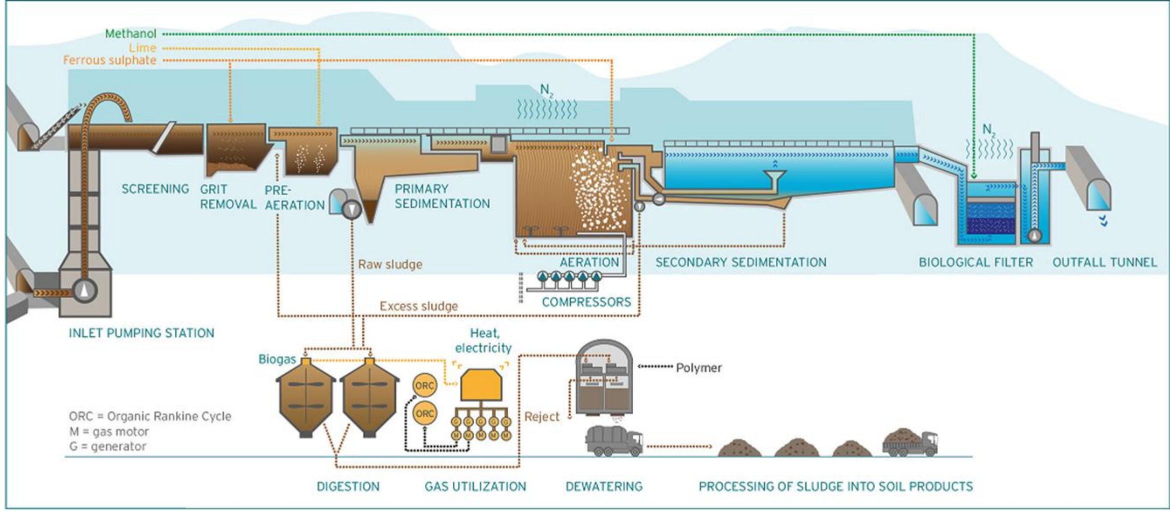
2. Status of the WWTP
Viikinmäki WWTP

- Viikinmäki WWTP, situated in Helsinki, Finland
- Operated by the Helsinki Region Environmental Services Authority HSY
- Q_{AVE} 270 000 m³/d
- PE > 1 M
  - app. 0,9 M persons + industrial load
- Typical municipal wastewater
  - Low industrial load (app. 10 %)
- "A coastal facility" – the catchment area has a long coastline and islands
  - Several earlier observations of seawater intrusion
- No drug industry but several hospitals



2. Status of the WWTP Viikinmäki WWTP

- Underground treatment plant
  – Excavated rock caverns
- Conventional activated sludge process with post denitrifying filters and mesophilic digestion of sludge
- Sludge is composted and used in landscaping and agriculture
- Future plans include an effluent polishing step for enhanced phosphorus removal
- A measuring campaign was performed in CWPharma 2 for effluent NO_2^-, DOC and Br^-
  – Analysed from 16 samples (15.3.-24.5.2021)
  à Estimated corresponding average yearly values *
  – Br^- > 1 mg/L observed in 8/16 samples (0,11 mg/L in the Fitness check!)



Parameter	Unit	2020 average effluent quality
COD_{Cr}	mg/l	41
BOD_{7ATU}	mg/l	4,9
TOC	mg/l	15,9
DOC	mg/l	14,6 *
SS	mg/l	4,6
Ntot	mg/l	4,2
NO_3-N + NO_2-N	mg/l	1,4
NO_2-N	mg/l	0,25 *
NH_4-N	mg/l	1,0
Ptot	mg/l	0,19
PO_4-P	mg/l	0,07
Br	mg/l	< 1–3 *

3. API monitoring campaigns

- **CWP Guideline:**
  - "If not already available, sampling campaigns for relevant APIs should be conducted at the WWTP effluent (e.g. 24h composite samples) for at least three days with dry-weather conditions"
    - "Note that concentrations of some API vary over the span of the week."

3. API monitoring campaigns Viikinmäki WWTP

- No regular API monitoring but API analyses have been made in several different projects
- Included in the Viikinmäki WWTP Feasibility study report:
  - A summary of projects with API samples
  - Results from CWPharma 2 (2 sampling days) by Aarhus University
  - Also 1 sampling day for the Fitness check
- NOTE: The API monitoring results were not used for AWT dimensioning in the preliminary design.

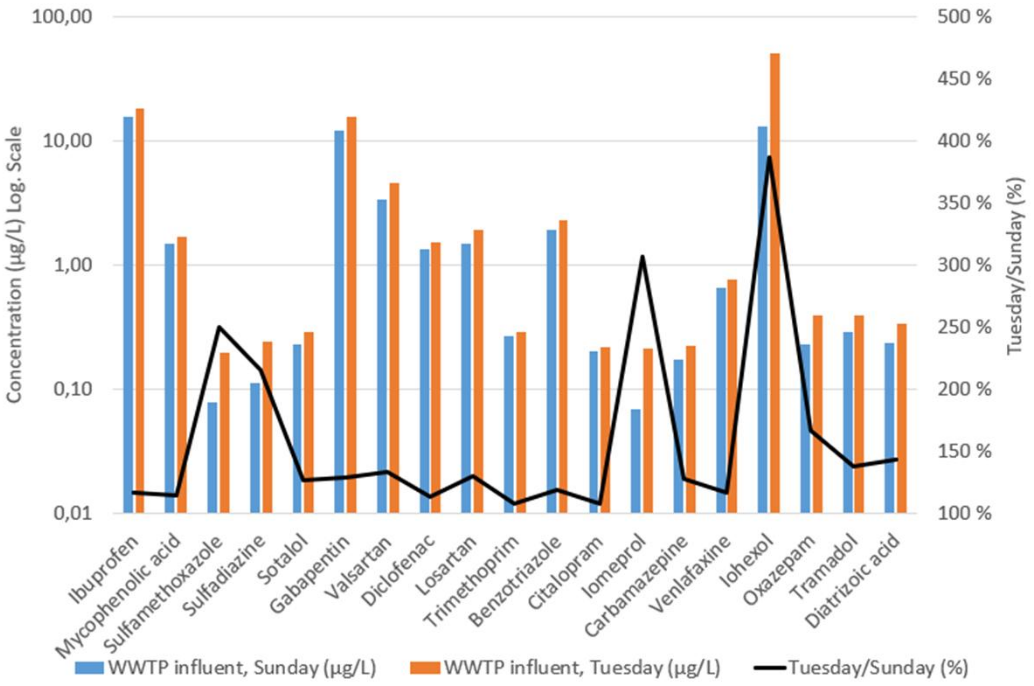
à The design was based on "typical" / literature values.

Date	Samples	Sample type	Reference
18.11.2013	WWTP influent and effluent	24 h flow based composite	Finnish study on micropollutants at 64 WWTPs in 2014 (only 5 APIs included)
7.7.2015	PAC jar test influent (= WWTP effluent) and effluent	grab samples	Not published
2019	WWTP effluent	24 h flow based composite	Occurrence and risks of active pharmaceutical ingredients in Vantaanjoki watershed, CWPharma[6]
10.1.2019 14.1.2019	ACTIFLO®Carb influent (= WWTP effluent) and effluents	grab samples	ACTIFLO® Carb piloting at Viikinmäki WWTP, CWPharma
29.9.2020	WWTP influent and effluent	24 h flow based composite	Finnish study on micropollutants at 18 WWTPs in 2020
30.5.2021 8.6.2021	**WWTP influent and effluent**	**24 h flow based composite**	**CWPharma 2**
7.6.2021	WWTP influent and secondary effluent (=before DN-filtration)	24 h flow based composite	CWPharma 2 WWTP Fitness check
15.9.2021	GAC filter influent (= WWTP effluent) and effluent	grab samples	GAC-piloting, CWPharma 2

HSY

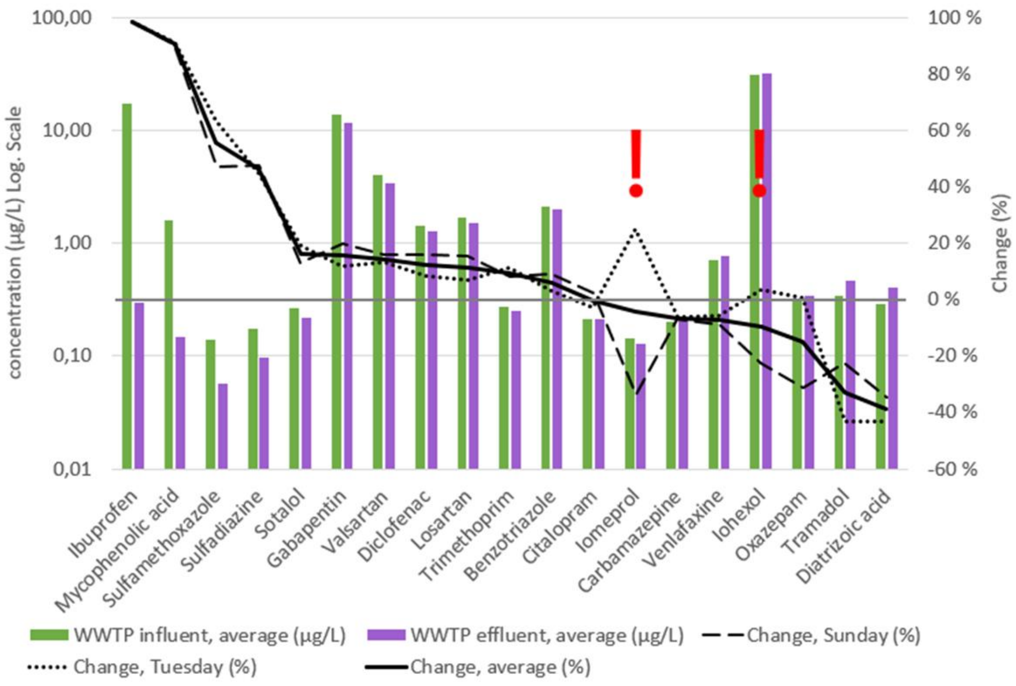
3. API monitoring campaigns
Viikinmäki WWTP

Sunday vs. Tuesday



- *Slightly higher flow on Sunday*

Influent vs. effluent



- *Effluent ~ previous day's influent*

Analyses by Aarhus University, only APIs with influent C>3*LOQ included

4. State of the art / knowledge of AWT

- **CWP Guideline:**
  - “A brief description of the available AWT technologies for API elimination along with an overview of reference WWTPs with the existing AWT in operation ”

4. State of the art / knowledge of AWT
Viikinmäki WWTP

- Short descriptions of the following process options, chosen in co-operation with KWB

1. GAC
   a) GAC filtration
   b) GAC filtration combined with P-removal
2. PAC
   a) PAC with a contact tank and cloth filter, microsieve or membrane separation
   b) PAC with deep bed filtration
   c) PAC addition in the activated sludge process
3. Ozonation
   a) Ozonation with MBBR
   b) Ozonation with sand or anthracite filter
   c) Ozonation prior to the current DN-filter
4. Ozonation and GAC filtration

5. Preliminary design of AWT technology

- **CWP Guideline:**
  - Define the design flow of the AWT (e.g. dry-weather peak, maximal flow of the WWTP)
  - Determine dosages (PAC, ozone) and GAC exchange frequency required to meet the API elimination target.
  - Evaluate potential integration of existing infrastructure (e.g. unused tanks, filter) and determine space requirements (e.g. additional tank volume).
  - Consider limitations of AWT technologies (bromate formation, sludge usage…) but also potential positive side effects (P removal, disinfection…)

Identifying potential barriers in the Fitness check module

5. Preliminary design of AWT technology Viikinmäki WWTP

Preliminary design was made for:

1. GAC
   a) GAC filtration
2. PAC
   a) PAC with a contact tank and microsieve separation
   c) PAC addition in the activated sludge process
3. Ozonation
   a) Ozonation with MBBR

Preliminary design earlier, to secure a reservation in the city underground zoning:

4. Ozonation and GAC filtration

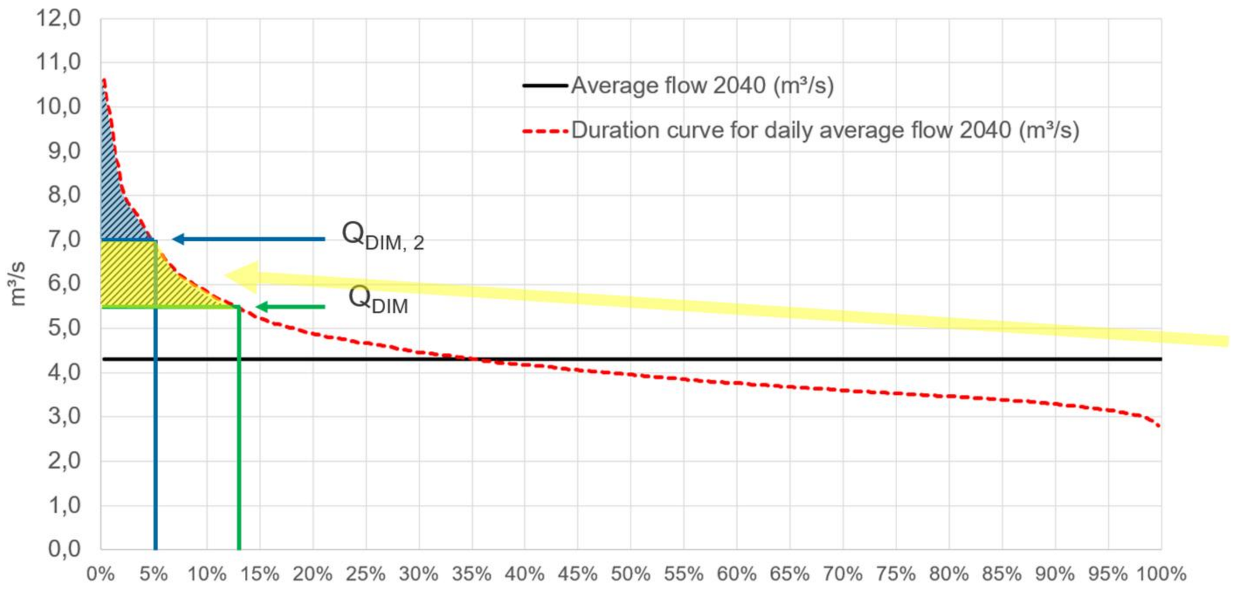
Possible barriers recognized:

- No space at the current treatment plant
- Sludge currently composted and used in landscaping and agriculture
  – Adding PAC to AS in conflict with this
- High bromide concentrations observed in the WWTP effluent
  – Risk of bromate formation in ozonation when Br^- >0,150 mg/L
- Houses will be built above the planned underground post-treatment
  – PAC storage above ground not welcome

5. Preliminary design of AWT technology Viikinmäki WWTP

Average duration curve of WWTP inflow:

- (Daily flows in order of magnitude)
- Based several years' flow data
- Scaled for 2040



Two alternative dimensioning flows:

- Q_{DIM} 5,5 m³/s
  - Dry weather peak flow
  - 96 % of yearly total flow included
  - 87 % of days Q < Q_{DIM}
- $Q_{DIM,2}$ 7,0 m³/s
  - Used earlier for process option 4
  - 98,5 % of flow
  - 95 % of days Q < $Q_{DIM,2}$
- Q_{DIM} vs. $Q_{DIM,2}$
  - Almost 30 % increase in size

  à 3,5 % increase in total flow treated

5. Preliminary design of AWT technology Viikinmäki WWTP

	1 a) GAC	2 a) PAC + filter	2 c) PAC in AS	3 a) O_3 + MBBR	4 O_3 + GAC
Footprint * (m²)	3 300	3 500	< 100	1 500	4 600
Footprint * $Q_{DIM, 2}$ (m²)	4 200	4 400		1 800	5 700
Carbon (m³ GAC/a tn PAC/a)	5 400	3 000	6 000	-	5 400 **
Other chemicals (tn/a)	-	Coagulant: 2 700 Flocculant: 200	-	(Oxygen: 1 600***)	(Oxygen: 1 600***)
Electricity (GWh/a)	5	3	*not estimated*	36 (22***)	38 ** (24***)
Other	GAC washwaters	Separate sludge treatment	Sludge treatment		GAC washwaters

*) For GAC, PAC and/or O_3 and PSA only
**) O_3 dosage and GAC breakthrough time may be different in a combination process
***) If liquid oxygen is purchased
Please note that the estimated electricity consumptions are strongly dependent on several factors such as ozone dose, method of PAC separation, GAC backwash frequency, and the hydraulics/pumping needed.

- Preliminary design for 1–3 was made in co-operation with KWB, using a KWB Excel template and based mainly on literature values and typical Finnish or Finnish values
- Preliminary design for 4 was made earlier by HSY (process design, based on literature values) and AFRY (lay-outs, excavations, equipment, CAPEX and OPEX)

6. Costs & 7. Overall evaluation

- **CWP Guideline:**
  - Estimate CAPEX and OPEX using national reference values or local boundary conditions
  - Consider also other criteria in the overall evaluation, e.g.
    - Maturity of the technology, references
    - Space requirements
    - Carbon footprint
    - Ease of maintenance
    - Staff qualification requirements
    - Robustness
    - Ecotoxicological considerations…

6. Costs
Viikinmäki WWTP

	1 a) GAC	2 a) PAC + filter	2 c) PAC in AS	3 a) O_3 + MBBR	4 O_3 + GAC
CAPEX					
Investment, $Q_{DIM, 2}$ (M €)	100 *	100 *	< 1 *	80 *	150
OPEX					
Carbon (M €/a)	3,5	5,4	10,8	-	3,5
Coagulant and flocculant (M €/a)	-	1,8	-	-	-
Electricity (M €/a)	0,5	0,3	**	3,6	3,8
Sludge disposal / washwater treatment (M €/a)	0,3	5,7	1,5	**	0,3
Other * (M €/a)**	0,5	0,6	**	0,7	1,1
Operational costs total (M €/a)	4,8	13,8	12,3	4,3	8,7
Operational costs total (€/m³)	0,04	0,10	0,09	0,03	0,06

*) Estimated, based on footprint and complexity of equipment compared to process option 4
**) Not estimated, deemed not significant for comparison
***) Maintenance, labour
Please note that the estimated investment and operational costs and the resulting differences between process options apply only with the conditions, assumptions and process design used in this study and large variations are possible.

7. Overall evaluation Viikinmäki WWTP

	1 a)	1 b)	2 a)	2 b)	2 c)	3 a)	3 b)	3 c)	4
Bromate risk*	++	++	++	++	++	-	-	0	-/0**
Compact /use of current infra-structure	0	0/-	0	0	++	+	0	+	-
Compatible with current sludge usage* **	++	++	+	+	-	++	++	++	++
P-reduction****	+	++	++	+	-	-	+	-	+
Operational costs	+		-		-	+			0
Investment costs	0		0		++	+			-
SUM	+5		+4		+3	+3			0/+1
Possible barriers?	no	no	space	space	sludge usage	Br-	Br-	space	Br-

*) From (-) high risk to (++) no risk.
**) A lower ozone dosage, producing less bromate, may be sufficient
***) (+) Separate sludge treatment needed
****) (+) Possible with modification, but may decrease hydraulic or API removal capacity and increase operating costs.

1. a) GAC filtration
   b) GAC filtration combined with P-removal
2. a) PAC with a contact tank and microsieve separation
   b) PAC with deep bed filtration
   c) PAC addition in the activated sludge process
3. a) Ozonation with MBBR
   b) Ozonation with sand or anthracite filter
   c) Ozonation prior to the current DN-filter
4. Ozonation and GAC filtration

Carbon footprints or LCA !?

Requirements vs. removal capacity!?

GAC filtration pilot procurement and preliminary testing

- In the CWP Guideline, piloting is a part of the Detailed planning module

- Piloting steps in CWPharma 2:
  - Designing the pilot
  - Purchasing the pilot
  - Preliminary testing and modifications
  - Hydraulic testing with virgin and regenerated GAC
  - API removal tests

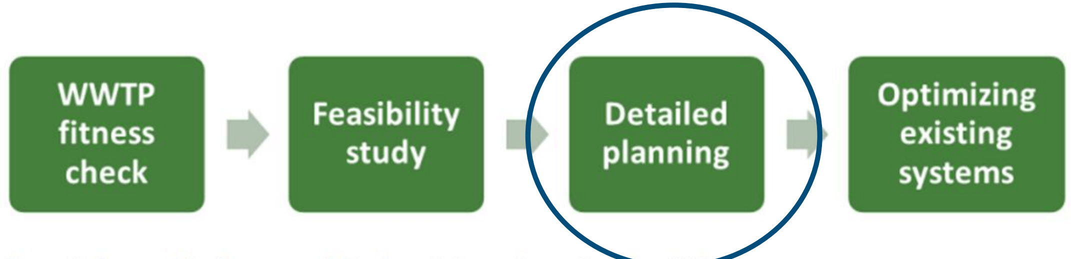


Figure 11: Four modules for a successful implementation and operation of an AWT.

GAC filtration pilot procurement and preliminary testing

Motivation for piloting

- GAC filtration is a mature technology

  à It can be designed without piloting
- Why piloting (future goals):
  - Comparing different non-fossil carbon sources
  - Testing activated biochar from HSY's sludge pyrolysis pilot plant?
  - Testing for combined P and API removal

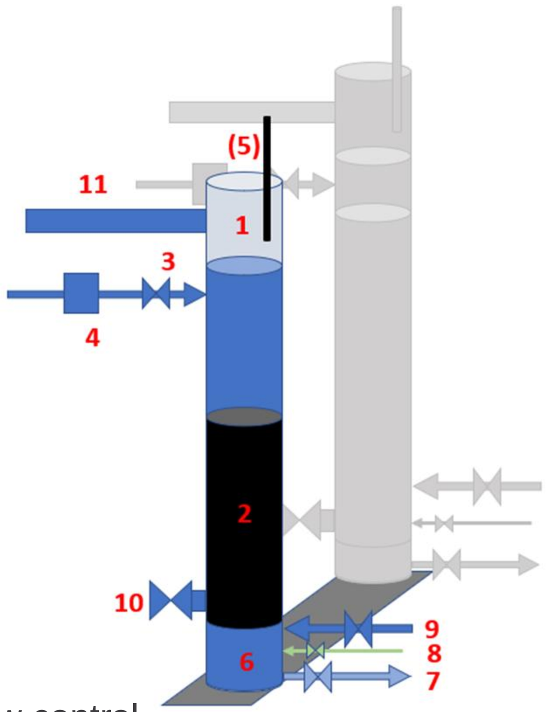
Goals in pilot design

- Ability to test also the hydraulic capacity and need for washing

  à A sufficiently large pilot
- Ability to compare reliably different GAC materials in field conditions

  à (At least) two parallel lines

GAC filtration pilot procurement and preliminary testing



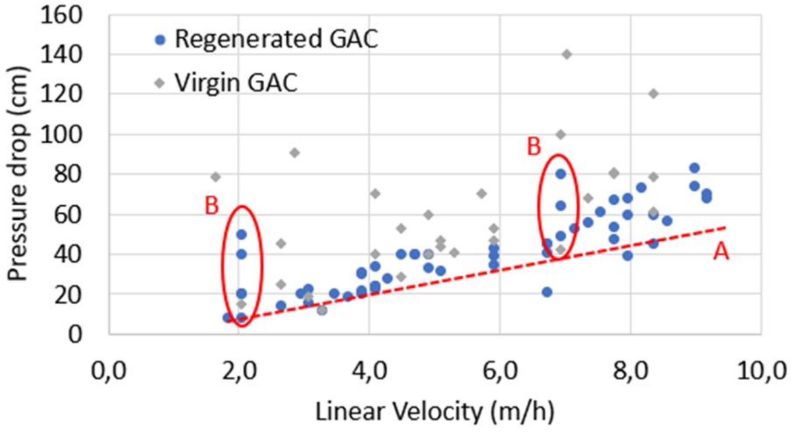
GAC pilot dimensioning (per column)

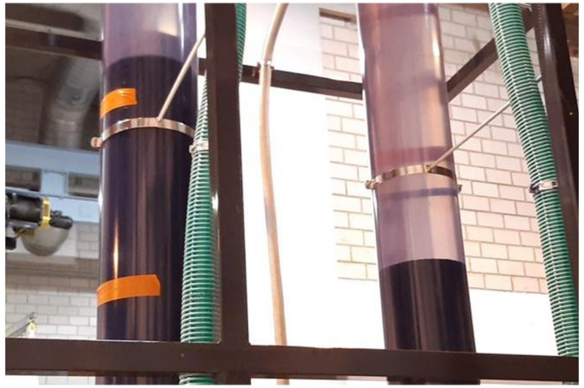
Parameter	Unit	Value
Diameter	m	0,25
Surface	m^2	0,05
Filter bed depth	m	3 *
Filter volume	m^3	0,15 *
Q_{AVE}	L/h	180
Q_{MAX}	L/h	400
Surface load, Q_{AVE}	m/h	3,7
Surface load, Q_{MAX}	m/h	8,0
EBCT, Q_{AVE}	min	50 *
EBCT, Q_{MAX}	min	23 *

*) The filter bed depth can be changed, which will impact the EBCT

1. Pilot columns
2. Filter material
3. Manual valve for influent flow control
4. Visual flow measurement
5. (Optional: surface measurement or alarm)
6. Bottom structure
7. Outflow
8. Air for cleaning
9. Backwash water
10. GAC extraction
11. Overflow for washwater and for hydraulic overload situations

GAC filtration pilot procurement and preliminary testing





Project reports

- Applying the CWPharma Guideline for advanced API removal – Feasibility study for Viikinmäki WWTP, GoA2.2: Applying recommendations for planning of API removal and plant optimization
- Procurement of and preliminary testing with a technical scale GAC pilot at the Viikinmäki WWTP, GoA2.2: Applying recommendations for planning of API removal and plant optimization

Thank you!

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