CWPharma 2

CLEAR WATERS FROM PHARMACEUTICALS

# 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

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## Chapter contributions (institution):

- Introduction (HSY)
- Ambition of the API elimination technology (HSY, KWB)
- Status of the WWTP (HSY, KWB)
- A summary of API monitoring campaigns at Viikinmäki WWTP (HSY)
- Evaluating different AWT options (HSY, KWB)
- Preliminary design of AWT technology (KWB, HSY)
- Costs (KWB, HSY)
- Overall evaluation (HSY, KWB)
- On implementing the CWPharma Guideline for advanced API removal (HSY)
- Appendix: Effluent quality (AU, Aarhus University, HSY, KWB)


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# Introduction

This report is part of the Clear Waters from Pharmaceuticals 2 (CWPharma 2) project and was funded by the EU's Interreg Baltic Sea Region Programme. It describes the implementation of the CWPharma Guideline for Advanced API Removal[1] for Viikinmäki WWTP and it has been made in close co-operation between KWB and HSY. The API results presented were analysed by Aarhus University.

The Viikinmäki WWTP is Finland's largest WWTP with 1.3 million PE. It is situated in Helsinki and operated by the Helsinki Region Environmental Services Authority HSY.

The CWPharma guideline describes several advanced wastewater treatment (AWT) processes for the removal of active pharmaceutical ingredients (API) and provides also a guideline for the implementation of API elimination technology.

There are four modules of implementation described in the CWPharma Guideline for advanced API removal: "WWTP Fitness check", "Feasibility study", "Detailed planning" and "Optimizing existing systems". This report is based on the "Feasibility study" module. Viikinmäki WWTP participated also in the CWPharma 2 "Fitness check"[3] where 83 WWTPs from countries surrounding the Baltic Sea were evaluated, 12 of them from Finland. The results for Viikinmäki are described in a separate report[3] and the API results are also included in this report.

The structure of this report is made based on CWPharma guideline, where the "Feasibility study" module is recommended to include:

- Ambition of the API elimination technology,
- Status of the WWTP,
- API monitoring campaigns,
- State of the art / knowledge of AWT,
- Preliminary design of AWT technology,
- Costs and
- Overall evaluation.

Preliminary design values was made for GAC-filtration, PAC with MBBR ozonation, PAC addition into the activated sludge process and the earlier design[4] for ozonation + GAC-filtration is also presented in this report.

On-site piloting, which is included in the module "Detailed planning" was also started at Viikinmäki WWTP as part of the CWPharma 2 and it is described in a separate report[5].

# Ambition of the API elimination technology

HSY's targets for the API elimination technology are sea protection and decreasing the API emissions into the environment. The Viikinmäki WWTP effluent is led to the Baltic Sea via a long effluent tunnel, and it has no impact on drinking water sources and little or no impact on the bathing waters.

Complying with anticipated future requirements is also a central goal, but currently API or micropollutant removal is not yet required in Finland. Therefore, it is not known which minimum reductions and/or maximum effluent concentrations must be achieved, and which pollutants will be monitored for proof of compliance. Thus, general or "typical European level" requirements need to be used at this stage. The renewal of the EU Urban Wastewater Treatment Directive (91/271/EEC) is expected to bring clarity to this issue.

The preliminary planning has been based on 80 % reduction as yearly average.

# Status of the WWTP

Viikinmäki WWTP is the largest WWTP in Finland with a PE of 1,3 M and with a relatively low portion of industrial load.

## Catchment area

Viikinmäki WWTP is a seaside facility with a long coastline, with wastewater collected also from islands (Figure 1).

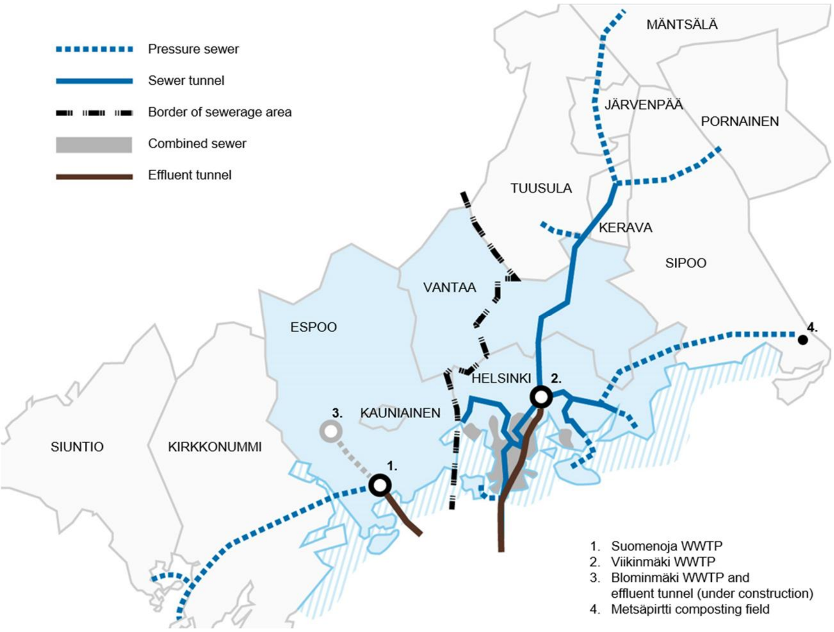


*Figure 1. The sewerage areas of Viikinmäki WWTP and Suomenoja/Blominmäki WWTP.*

In the past years there have been several observations of seawater entering the sewer network through leaks or backwards through overflows, often detected by a sudden increase of wastewater conductivity, measured at the WWTP. Repairs and modifications have been made after such incidents, but there is always risk of seawater intrusion. The sources of possible continuous, low intrusions are hard to find and to eliminate.

Only 10 % of the influent flow comes from industrial sources. There is no drug industry at the catchment area of Viikinmäki WWTP but there are several hospitals whose impact can be seen in the API results presented in the Appendix.

## Viikinmäki WWTP

The preliminary design for API removal has been made using the estimated load of 2040. The influent load of 2020 and the estimated load for 2040 are presented in Table 1 and the effluent concentrations in Table 4. The API concentrations of three samplings made in CWPharma 2 are presented in the Appendix.

*Table 1. Viikinmäki WWTP influent flow and loads.*

| Parameter | Load 2020 | Estimated load 2040 |
|---|---|---|
| Average flow, $Q_{AVE}$ (m³/d) | 300 000 | 370 000 |
| $BOD_{7ATU}$ (kg/d) | 68 000 | 91 000 |
| $COD_{Cr}$ (kg/d) | 150 000 | 200 000 |
| SS (kg/d) | 86 000 | 100 000 |
| Total phosphorus, P (kg/d) | 1 700 | 2 200 |
| Total nitrogen, N (kg/d) | 14 000 | 19 000 |

Viikinmäki WWTP is a pre-denitrifying activated sludge plant with post-denitrifying filters. Phosphorus is removed by precipitation with ferrous sulphate and methanol is used as the carbon source to the denitrifying filters. Calcium hydroxide is used to increase alkalinity in the activated sludge process. Sludge is digested and dried. Polymers are used in sludge drying. The biogas produced in digestion is used for production of electricity and heat. The process scheme is presented in Figure 2.

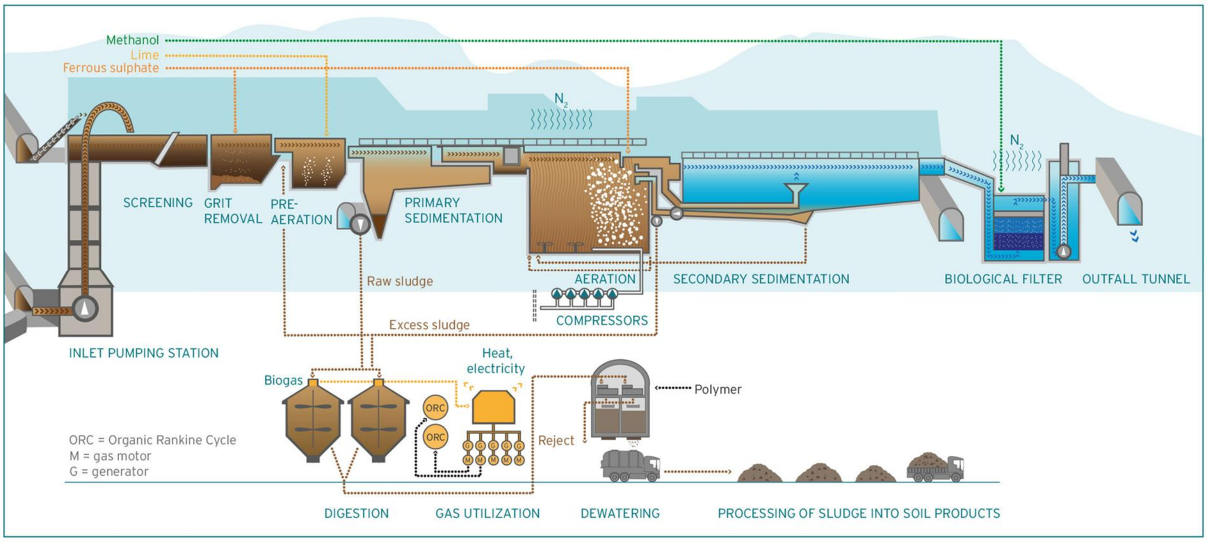


*Figure 2. Viikinmäki WWTP process scheme.*

The future plans for a possible WWTP upgrade include an effluent polishing step for phosphorus removal (chemical precipitation and disc filtration), separate treatment for by-pass waters of the biological treatment and a full-scale deammonification process for reject waters from sludge dewatering (currently 15–20 % of the reject waters are treated biologically).

## Potential barriers and limitations (based on the "WWTP fitness check" module)

There are several potential barriers limiting the feasible options or causing requirements for a post treatment at Viikinmäki WWTP. Bromide values up to 3 mg/L were observed during a monitoring campaign in spring 2021 (see Table 5 and Appendix), whereas the safe level for bromide at an ozonation process, which oxidizes bromide into bromate, is 0.150 mg/L[1]. This may be overcome with a post treatment step where bromate is reduced again, but it can be costly and also not yet well investigated.

The digested and dried sludge from Viikinmäki WWTP is used for landscaping and agriculture. This means that if powdered activated carbon is used at a post treatment process, the PAC-sludge must be treated separately. Also adding PAC to the activated sludge process is not an option. However, sludge usage may have to change in the future, as there has been rising public concern on the organic micropollutants in WWTP sludge which may be a driving force for e.g. pyrolysis to produce a sludge product where organic micropollutants have been eliminated or to incinerate sludge for energy production.

There is not enough space for a post treatment step at the current facility and a separate area is needed, which is costly. The current plans for the post treatment step are that it will be built underground. The city is planning a residential area above the site. Therefore, the use of space above ground must be limited to minimum.

# A summary of API monitoring campaigns at Viikinmäki WWTP

Several groups of micropollutants, such as heavy metals, VOCs, phenols and phthalates, are monitored regularly in the Viikinmäki WWTP effluent and influent and limits and upstream control of industrial sewage have been implemented for many decades, but there is no regular monitoring of APIs so far.

APIs have been measured in several separate projects that are listed below in Table 2 together with references. In CWPharma 2 APIs were measured in 24 h composite samples on three separate days from the WWTP effluent, twice from the WWTP influent and from two effluent grab samples during the GAC filter piloting. The API monitoring results were not used in this feasibility study for the preliminary process dimensioning, which was based on literature values.

*Table 2. A summary of API monitoring in different projects at Viikinmäki WWTP.*

| 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[8] * |
| 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<br>14.1.2019 | ACTIFLO®Carb influent (= WWTP effluent) and effluents | grab samples | ACTIFLO® Carb piloting at Viikinmäki WWTP[7], CWPharma |
| 29.9.2020 | WWTP influent and effluent | 24 h flow based composite | Finnish study on micropollutants at 18 WWTPs in 2020[9] |
| 30.5.2021<br>8.6.2021 | WWTP influent and effluent | 24 h flow based composite | CWPharma 2. Results presented in the Appendix |
| 7.6.2021 | WWTP secondary effluent (before DN-filtration) | 24 h flow based composite | CWPharma 2 WWTP Fitness check[2,3]. Results presented in the Appendix |
| 15.9.2021 | GAC filter influent (= WWTP effluent) and effluent | grab samples | CAG-piloting, CWPharma 2 [5] |

*) only 5 APIs included

# Evaluating different AWT options

The feasibility of different advanced wastewater treatment (AWT) options for Viikinmäki WWTP using GAC, PAC or ozonation were evaluated based on the CWPharma Guideline[1], in co-operation between HSY and KWB. These are presented below as options 1–3.

AWT option 4 including both ozonation and GAC filtration was used in earlier preliminary design which was made for a space reservation in the Helsinki underground city plan.[4]

Unless stated otherwise, all AWT processes are to be placed after the current process.

## 1 a) GAC filtration

Activated carbon has a very high surface area and API removal with activated carbon is based on adsorption on the surface of the filter media.

Granular activated carbon (GAC) is used as a filter, which can be a downflow filter or for example a fluidised upflow filter. The contact time, defined as empty bed contact time (EBCT) should typically be at least 20 minutes.

Over time, GAC gets loaded with APIs and has to be exchanged with fresh or reactivated GAC to prevent a breakthrough of API. GAC filter material should be exchanged or reactivated typically after 20 000 – 30 000 bed volumes of wastewater have been treated, depending on wastewater quality. Reactivating GAC significantly decreases the need to use fresh GAC. Typically, 10–20 % of GAC is lost during reactivation and must be replaced with fresh GAC.

Important water quality parameters are dissolved organic carbon (DOC) as it is also adsorbed on activated carbon and TSS as it has an impact on filter clogging, hydraulic capacity and backwash intervals needed.

## 1 b) GAC filtration + P removal

GAC filtration can also be combined with effluent polishing for phosphorus removal by e.g. adding a coagulation chemical before filtration and using a combined filter with sand and GAC layers.

API removal combined with P-removal could replace the separate phosphorus removal step that is planned for Viikinmäki WWTP – or it could promote converting the planned phosphorus removal step into phosphorus recovery by acting as a second phosphorus removal step, ensuring high effluent quality.

Including phosphorus removal has an impact on filter dimensioning and also on the backwashing needs due to chemical sludge.

## 2 PAC

API removal with powdered activated carbon (PAC) is also based on API adsorption onto the PAC surface. Compared to GAC, PAC cannot be used as filter material. It is mixed to the wastewater and needs to be separated with e.g. a filter or membrane.

PAC cannot be regenerated, which may lead to higher operational costs, and depending on the origin of the activated carbon and the source of energy used in GAC reactivation, also a higher carbon footprint compared to GAC.

When PAC is used as post treatment, the sludge can be treated separately which is necessary if the sludge from the WWTP main process is used for agriculture. This, however, increases the needed PAC dosage, as recycling PAC sludge into the activated sludge process enhances the overall API removal. Also, the space requirement and investment costs are higher due to the separate sludge treatment needed.

PAC cannot be stored at excavated underground facilities due to dust explosion risk. This creates a need for above ground storage for the otherwise underground treatment planned for Viikinmäki WWTP. It should also preferably be located close to its dosage point to avoid clogging of pipes during transport, which limits the placement options.

DOC is an important water quality parameter as it is also adsorbed onto the PAC.

### 2 a) PAC dosage prior to deep bed filtration

When (deep bed) filtration is used for separating PAC from the wastewater, the contact time needed for API removal can be achieved in the filter and thus no separate contact tank is needed.

This treatment option can also be combined with phosphorus removal by either using an anthracite filter or adding a coagulation chemical before filtration, but its effect on the hydraulic capacity must be considered.

### 2 b) PAC dosage prior a filter, with a contact tank

When using a different filter type, such as discfilters or membrane separation, a sufficient contact time, typically 30–60 minutes, must be provided before filtration. Depending on the filter type used for PAC separation, a coagulant, a flocculant or both may be needed. With coagulant addition, also phosphorus can be removed. Coagulant addition will produce chemical sludge and the increased solids load must be taken into consideration in dimensioning the filter the possible separate treatment needed for filter sludge. The retention time in the coagulation and flocculation tanks can decrease the retention time needed in the separate PAC contact tank.

Separating PAC with discfilters and with a Mecana pile cloth filter was studied in CWPharma with two different PAC products and dosages of 10, 20 and 30 mg/L[10, 11].

### 2 c) PAC addition into the activated sludge process

PAC can also be added in the activated sludge process, in which case a higher dosage is needed due to the presence of more DOC. Compared to post treatment, the investment is dramatically smaller, but for the Viikinmäki WWTP there are several barriers including sludge usage, post sedimentation and sludge treatment capacity and the storage of PAC.

### 3 Ozonation

API removal by ozonation is based on oxidation. Important water quality parameters are DOC and nitrite (ozone consumption, dimensioning) and bromide (risk of bromate formation). A typical ozone dose is 0.3–0.9 $mgO_3/mgDOC$ + 3.43 mg $O_3/mgNO_2$-N.

There are some differences in the API removal capacity between ozonation and activated carbon, as certain compounds cannot be removed by adsorption but can be degraded with ozonation and vice versa.

Ozone must be produced from oxygen on site, and the residual ozone in the off-gas must be destroyed using a thermic or a catalytic ozone destructor.

Producing ozone from oxygen has a high energy consumption, roughly equivalent to energy consumption for aeration of the activated sludge process. Also, oxygen must either be purchased, or it must be produced from air. If oxygen is produced from air on site, it more than doubles the energy consumption of ozonation.

In ozonation there is some risk in producing by-products that could potentially be even more harmful than the original compounds, and if the wastewater contains bromide, bromate is formed. Ozonation requires a post treatment step to eliminate or reduce formed oxidation by-products that sometimes can have adverse ecotoxicological effects. The choice of the post treatment option may have a significant impact on the space requirement and operational costs.

After ozonation, the wastewater has a high oxygen concentration which may be beneficial or problematic depending on the post treatment. Post treatment for bromate removal may be particularly costly, as it requires biological treatment in anoxic conditions.

### 3 a) Ozonation with MBBR as post treatment

Post treatment with MBBR is relatively compact, but it has little impact on water quality and there is no phosphorus or bromate reduction

### 3 b) Ozonation with sand or anthracite filter as post treatment

If a sand or anthracite filter is used for post treatment after ozonation, it can be combined with phosphorus removal by adding a coagulation chemical before filtration or using anthracite as filter material.

There is no bromate reduction.

### 3 c) Ozonation prior to the current DN-filter

Using ozonation prior to the current DN-filter of the Viikinmäki WWTP would enable using the DN-filters for bromate reduction. However, due to the high oxygen concentration after ozonation, the carbon dosage would be significantly increased, and the nitrate removal capacity may decrease.

Also, there is not enough space for ozonation at the treatment plant.

### 4 Ozonation and GAC filtration

If ozonation is combined with GAC filtration, a higher overall API removal can be achieved as some API are more efficiently removed by ozonation and some by activated carbon. Also, the ozone dosage could possibly be decreased, decreasing also the potential bromate formation.

Activated carbon does not remove bromate, but it does remove other ozonation by-products acting as a more efficient post treatment for ozonation.

The footprint of the treatment option is comparable to ozonation with sand or anthracite filtration and the operation costs include both a high energy consumption of ozonation and the need to reactivate and replace GAC.

An activated carbon filter can also be used as a biologically enhanced activated carbon filter (BAC), particularly after ozonation, which breaks the DOC into more readily biodegradable compounds. Organic compounds are consumed by the biological activity, which may slow down the loading of the activated carbon. Also, some API may be removed or transformed by the biological activity itself.

# Preliminary design of the AWT technology

Preliminary design was made for four selected process options in this project: 1 a), 2 a), 2 c) and 3 a) based on the CWPharma Guideline[1], in co-operation between HSY and KWB. Preliminary design for process option 4 had been made earlier to enable making a space reservation in the city underground zoning[4]. The numbering of process options is similar to the numbering used in the previous chapter: Evaluating different AWT options.

The dimensioning was mainly made using an Excel-template developed by KWB. The values used were either "typical"/literature/German values suggested by KWB, typical Finnish values or based on the earlier preliminary planning[4] when suitable.

In addition to the space and energy requirements of the AWT-process themselves, pumping, sieving and sludge treatment are needed. Sieving is needed because in wintertime, part of the snow collected from city streets is melted into the effluent wastewater between Viikinmäki WWTP and the planned site for AWT and there is grit and some waste in the snow.

The electricity consumption for pumping (lifting) water at some stage of the treatment process depends on the hydraulic design and limitations, and a detailed hydraulic design has not been made at this stage.

## Dimensioning flows and parameters

Process dimensioning is made for the predicted load in 2040.

Two alternative dimensioning flows were compared: the dry weather maximum flow ($Q_{DIM,\ max\ dry\ weather}$) and the same flow that was used in the earlier design made for the space reservation ($Q_{DIM,\ 2}$)[4].

*Table 3. Predicted flows for 2040.*

| Flow | $m^3/d$ | $m^3/h$ | $m^3/s$ |
|---|---|---|---|
| $Q_{AVE}$ | 372 000 | 15 500 | 4.3 |
| $Q_{MAX}$ | 933 000 | 39 000 | 10.8 |
| $Q_{MIN}$ | 173 000 | 7 200 | 2.0 |
| $Q_{DIM,\ max\ dry\ weather}$ | 475 000 | 20 000 | 5.5 |
| $Q_{DIM,\ 2}$ * | 605 000 | 25 000 | 7.0 |
| $Q_{MAX}$ ** | 778 000 | 32 000 | 9.0 |

*) The dimensioning flow used in earlier process design[4]
**) The maximum flow through process used in earlier process design[4]

The Viiikinmäki influent flow duration curve (daily average flows in order of magnitude), based on several year's flow data and scaled for the year 2020, is presented in Figure 3.

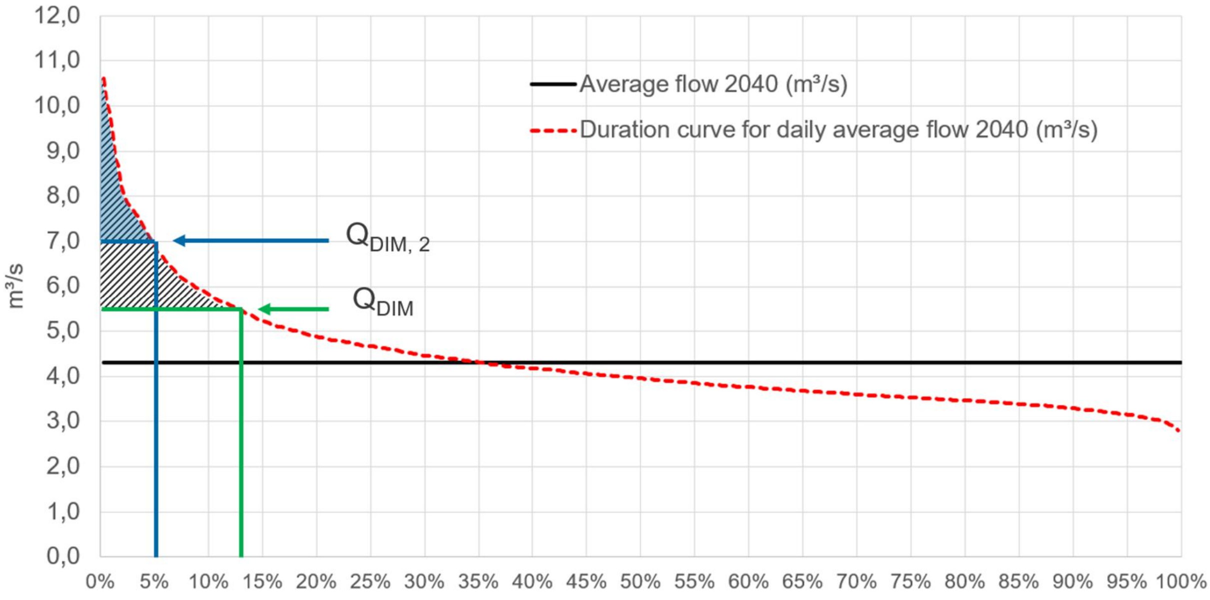


*Figure 3. The influent flow duration curve and the dimensioning flows $Q_{DIM}$ (max dry weather flow) and $Q_{DIM,2}$.*

With the dimensioning flow $Q_{DIM,2}$ of 5.5 m³/s, only 4 % of the yearly flow will not be treated (Figure 3, the striped area above the 5.5 m³/s line in) or the hydraulic retention times will be below the design value during 13 % of the days. With the higher dimensioning flow $Q_{DIM,2}$ of 7.0 m³/s the values are 1.5 % of flow and 5 % of days. Thus, an almost 30 % difference in the hydraulic capacity is equivalent to only 3.5 % of the total yearly flow or retention times over dimensioning values in 8 % of the days.

The wastewater quality is presented in the Table 4.

*Table 4. Water quality parameters at the WWTP effluent, average concentrations in 2020.*

| Parameter | Unit | Value |
|---|---|---|
| $COD_{Cr}$ | mg/l | 41 |
| $BOD_{7ATU}$ | mg/l | 4.9 |
| TOC | mg/l | 15.9 |
| DOC | mg/l | 14.6 * |
| SS | mg/l | 4.6 |
| $N_{tot}$ | 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 |
| $P_{tot}$ | mg/l | 0.19 |
| $PO_4$-P | mg/l | 0.07 |
| Br | mg/l | < 1–3 ** |

*) Based on the DOC/COD and $NO_2$-N/$NO_3$-N ratios during the measuring campaign in 2021, part of the CWPharma 2 project, and on the 2020 average concentrations of COD and $NO_3$-N in 2020. The DOC/TOC ratios would result in a slightly lower DOC value.
**) Based on the measuring campaign in 2021, part of the CWPharma 2 project.

## 1 a) GAC filtration

The dimensioning for GAC filtration, based on the KWB template is presented in Table 5.

*Table 5. Dimensioning of GAC filtration.*

| Parameter | Unit | Value |
|---|---|---|
| EBCT | min | 20 |
| Hydraulic load | m/h | 6 |
| Filter (GAC) depth | m | 2.0 |
| Filter area | $m^2$ | 3 300 |
| Filter volume | $m^3$ | 6 600 |
| *Filter area with $Q_{DIM,2}$* | *$m^2$* | *4 200* |
| *Filter volume with $Q_{DIM,2}$* | *$m^3$* | *8 400* |
| GAC exchange frequency | BV (bed volumes) | 25 000 |
| GAC consumed | $m^3/a$ | 5 400 |

The backwash water can possibly be pumped to the beginning of the main treatment process or treated separately if it is not feasible. The sludge consists mainly of solids separated from the wastewater but also a small portion of GAC particles.

## 2 b) PAC dosage prior a filter, with a contact tank

Separating PAC from wastewater using discfilters was piloted in CWPharma[10]. Discfilters have a small footprint compared to the filter area, but a coagulant and flocculant are needed for separating PAC, as the filter is a microsieve. The dimensioning of PAC addition before discfilters is presented in Table 6.

A separate contact tank is needed. The PAC contact tank volume can possibly be diminished as adsorption takes place also during coagulation and flocculation.

*Table 6. Dimensioning of PAC with a contact tank and membrane separation.*

| Parameter | Unit | Value |
|---|---|---|
| PAC dose | mgPAC /mgDOC | 1.5 |
| | mg/L | 22 |
| PAC consumption | tn/d | 8.2 |
| | tn/a | 3 000 |
| PAC contact time | min | 30 (20*) |
| PAC contact tank volume | m³ | 9 900 (6 600*) |
| Coagulation and flocculation contact time | min | 15 |
| Coagulation and flocculation contact tank volume | m³ | 5 000 |
| *PAC contact tank volume with $Q_{DIM,2}$* | *m³* | *12 600 (8 400*)* |
| *Coagulation and flocculation contact tank volume with $Q_{DIM,2}$* | *m³* | *6 300* |
| Coagulant** dose | mg Al/L | 2 |
| Coagulant consumption | tn/a | 2 700 |
| Flocculant dose | mg/L | 1.5 |
| Flocculant consumption | tn/a | 200 |
| Filter hydraulic load | m/h | 5.4 |
| Filter area | m² | 3 700 |
| Filter footprint (app.) | m² | 1 000 |
| *Filter area with $Q_{DIM,2}$* | *m²* | *4 700* |
| *Filter footprint with $Q_{DIM,2}$* | *m²* | *1 200* |
| PAC sludge produced | tn TS/a | 4 400 |
| | % TS | 10 |
| | tn/a | 44 000 |

*) A lower PAC contact time may be applied as adsorption continues during coagulation and flocculation.
**) polyaluminum chloride

## 2 c) PAC into the activated sludge process

When PAC is dosed in the activated sludge process, a higher dosage can be anticipated, as the DOC entering the activated sludge process is higher than effluent DOC. On the other hand, the contact time is much higher. The dosage presented in Table 7 is expressed in relation to effluent DOC and a dose twice as high as in post treatment is used.

*Table 7. Dimensioning of PAC dosage into the activated sludge process.*

| Parameter | Unit | Value |
|---|---|---|
| PAC dose | mgPAC / mg(effluent)DOC | 3.0 |
| | mg/L | 44 |
| PAC consumption | tn/d | 16.4 |
| | tn/a | 6 000 |
| Increase in sludge production (after digestion) | tn TS/a | 3 600 |
| | % TS | 30 |
| | tn/a | 12 000 |

No separate contact tanks are needed, but space is needed for PAC storage, which must be situated above ground, and the dosage equipment.

PAC deliveries every 2–3 days are needed with a bulk delivery size of 40 tn.

## 3 a) Ozonation with MBBR as post treatment

The dimensioning of ozonation with MBBR as post treatment is presented in table 8 .

*Table 8. Dimensioning of ozonation.*

| Parameter | Unit | Value |
|---|---|---|
| Ozone dose | mgO3/mgDOC | 0.7 |
| Ozone consumption | mg $O_3$/L | 11.1 * |
| | tn $O_3$/a | 1 600 ** |
| HRT for ozonation | min | 20 |
| Reactor volume | $m^3$ | 6 600 |
| *Reactor volume with $Q_{DIM, 2}$* | $m^3$ | 8 400 |
| HRT for MBBR | min | 10 |
| MBBR reactor volume | $m^3$ | 5 000 |
| *MBBR reactor volume with $Q_{DIM, 2}$* | *$m^3$* | *6 300* |
| Energy consumption for ozone production | kWh/kg $O_3$ | 9 |
| | MWh/a | 15 000 |

*) 0.7 $mgO_3$/mgDOC + 3.43 $mgO_3$/g $NO_2$-N
**) 95 % gas transfer efficiency

Ozone must be produced from oxygen, which may either be purchased or produced from air with a PSA unit.

*Table 9. Oxygen for ozonation.*

| Parameter | Unit | Value |
|---|---|---|
| Oxygen required | kg $O_2$/kg $O_3$ | 10 |
| | tn $O_2$/a | 16 000 |
| | tn $O_2$/d | 43 |
| Energy consumption for oxygen production | kWh/kg $O_2$ (kWh/kg $O_3$) | 1.1 (11) |
| | MWh/a | 17 000 |

If oxygen is purchased, daily deliveries of over 40 tn are needed. If oxygen is produced on site, the annual energy consumption for producing both oxygen and ozone is app. 30 GWh.

## 4. Ozonation and GAC filtration

The earlier design made for a reservation in the underground city zoning[4] included both ozonation and GAG filtration. There were some differences to the dimensioning for GAC filtration and ozonation in process options 1 and 3:

- The dimensioning flow used was 7 m³/s ($Q_{DIM,2}$).
- The contact time used for ozonation for $Q_{DIM,2}$ was 14 minutes, and the reactor volume was 6 000 m³.
- EBCT used for GAC filtration for $Q_{DIM,2}$ was 30 minutes, and the filter volume was 12 600 m³.
- A higher GAC-filter depth of 3 m and a higher surface load were used, resulting in a filter area of 4 200 m².

The lay-out of the underground process is presented in grey in Figure 4, with the GAC-filters and ozonation (ozone production and contact tanks) and PSA marked in the picture. The above ground usage for the emergency exits is marked in turquoise. The white rectangles inside the grey area are solid rock, as the excavated halls can only have a limited width. Other space requirements are influent pumping station, screens, storage and electrical facilities etc.

It should be noted that the lay-out has been made for space reservation purposes, using preliminary dimensioning, and the goal has not been to make it as compact as. Also, from the point of view of estimating future investment and operational costs, a very conservative or safe approach, particularly as the future requirements are not known, has been deemed necessary. However, in a combination process, smaller retention times or a smaller ozone dose are likely to be sufficient for the same API removal as in ozonation and GAC filtration alone.

Space is reserved also for separate treatment of solids of the dirty backwash water, in case it is not feasible to pump it to the main treatment process.


*Figure 4. Process lay-out for reservation in underground city zoning[4]. The light blue rectangles are emergency exits with structures above ground.*

## A summary of process design

The footprints presented in Table 10 below include the AWT process basins and filters and the PSA unit for process option 3 (see Figure 4 for process option 4). Additional space is needed in all post treatment options for pumping, screening, storage, maintenance facilities etc. The space requirements are assumed to be close to each other for all process options. A basin depth of 6 m was used for the PAC contact tank, coagulation and flocculation.

The footprints presented for option 4 in Table 10 are based on the same design values as options 1–3 to make them comparable and they are partly different from the original design.

The electricity consumption is based on the earlier design[4], and includes also pumping etc. 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.

*Table 10. The footprint of AWE and consumption of chemicals and electricity for different treatment options.*

| | 1 a)<br>GAC | 2 b)<br>PAC + filter | 2 c)<br>PAC in AS | 3 a)<br>$O_3$ + MBBR | 4 *<br>$O_3$ + GAC |
|---|---|---|---|---|---|
| Footprint **<br>($m^2$) | 3 300 | 3 500 | < 100 | 2 400 | 4 900 |
| Footprint **<br>$Q_{DIM,2}$ ($m^2$) | 4 200 | 4 400 | | 3 100 | 6 200 |
| Carbon<br>($m^3$ GAC/a<br>tn PAC/a) | 5 400 | 3 000 | 6 000 | - | 5 400 |
| Other chemicals<br>(tn/a) | - | Coagulant:<br>2 700<br>Flocculant:<br>200 | - | *(Oxygen:<br>1 600***)* | *(Oxygen:<br>1 600***)* |
| Electricity<br>(GWh/a) | 5 | 3 | *not estimated* | 36<br>*(22***)* | 38<br>*(24***)* |
| Electricity<br>(kWh/$m^3$) | 0.03 | 0.02 | | 0.26<br>*(0.16***)* | 0.28<br>*(0.17***)* |
| Other | GAC backwash water | Separate sludge treatment | Impact on sludge volume | | GAC backwash water |

*) Smaller $O_3$ dosage, GAC exchange frequency and/or contact times may be sufficient in a combination process, which has not been taken into account in the preliminary design
**) For GAC, PAC and/or O3 and PSA only
***) If liquid oxygen is purchased

The total energy consumption of the current Viikinmäki WWTP in 2020 was 40 GWh (0.36 kWh/$m^3$) and the equivalent consumption for the estimated load in 2040 is 50 GWh. Thus, depending on the AWT, the total energy consumption of wastewater treatment can increase significantly.

# Costs

The operational costs for different treatment options are based on the consumption of carbon, chemicals and electricity as well as costs for maintenance and personnel. The unit prices used are presented in Table 11. The unit prices are either based on the values used in the preliminary design of option 4[4], other typical Finnish prices or typical German prices used on the KWB template.

*Table 11. Unit costs for operation.*

| Parameter | Unit | Value |
| --- | --- | --- |
| PAC | €/tn | 1 800 |
| GAC (new) | €/m³ | 800 |
| GAC (regenerated) | €/m³ | 500 |
| PAC sludge disposal | €/tn | 130 |
| Coagulant* | €/tn | 280 |
| Flocculant | €/tn | 5 000 |
| Electricity | €/kWh | 0.10 |
| Personnel | €/person/a | 60 000 |

*) polyaluminum chloride

The investment costs of process options 1-3 are estimated based on their footprint and need for equipment compared to option 4 where preliminary design[4] had been made earlier, and they are presented for $Q_{DIM,2}$ in Table 12. All post treatment options (1. a), 2. a), 3. a) and 4 are assumed to be placed underground and excavation costs are included.

*Table 12. Investment costs and yearly operational costs.*

| | 1 a) GAC | 2 b) 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 | 90 | 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 / backwash water 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 |
| Specific operational costs total (€/m³) | 0.04 | 0.10 | 0.09 | 0.03 | 0.06 |

*) $O_3$ dosage and GAC exchange frequency and/or contact times may be smaller in a combination process, which has not been taken into account in the preliminary design
**) Not estimated, deemed not significant for comparison
***) Maintenance, labour

In process option 2, the coagulant and flocculant needed for separating PAC when using a cloth filter or microsieve and separate sludge disposal form a significant part of the treatment cost.

In process option 2 c) PAC addition to the activated sludge process, the sludge treatment cost is calculated for the PAC sludge only. The possible increase in the cost of treating the whole activated sludge volume is not included in process costs, because it is estimated that having some other driver for changing the sludge disposal method would be a prerequisite of using this process option.

Using purchased liquid oxygen instead of producing it on site would increase the yearly operational costs of process option 3 a) Ozonation with MBBR and 4) Ozonation and GAC filtration with roughly 0,6 M € (estimated price 140 €/tn).

It should be noted 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.

# Overall evaluation

The preliminary design was made for two dimensioning flows: 5.5 and 7.0 $m^3/s$. The choice of the dimensioning flow has a high impact on the footprint and investment costs.

Ozonation appears to be a highly problematic option, as high bromide concentrations have been observed in the Viikinmäki effluent. As Viikinmäki is a seaside WWTP, there is always a risk of bromide-rich seawater entering the sewage system. Also, the high energy requirement of ozonation conflicts strongly with HSY's goals for reducing energy consumption and achieving energy independence in wastewater treatment. On the other hand, if the energy used is fossil-free, it is a better option than activated carbon from a carbon footprint point of view.

PAC as post treatment has earlier been deemed unfeasible, due to the above-ground space requirement for PAC storage, which is in conflict with the city planning. Also, as PAC cannot be regenerated, its carbon footprint is higher compared to GAC.

From the point of view of investment costs, adding PAC to the activated sludge process is a very attractive option. However, the operational costs are high, due to the estimated higher dosage needed compared to post treatment. Also, the current use of sludge in landscaping and agriculture is a barrier for this type of PAC usage. Other issues are the treatment plant's growing influent load vs. its capacity, as well as the need for above-ground storage, ideally close to the dosage point.

From the process options evaluated here, GAC filtration appears to be the best option. It has several benefits such as a broad API removal, low energy consumption compared to ozonation and no risk of formation of toxic side-products such as bromate. Compared to PAC, the possibility of reactivation and the potential for using non-fossil based or even by-product or waste-based carbon decreases the carbon footprint. Also the above-ground space requirements are minimal.

Some API and micropollutants are not adsorbed on activated carbon and a more comprehensive API removal would be achieved with combining ozonation and GAC, which was the base for the design made for the underground zoning reservation[4]. From process evaluation purposes, it is problematic that the future requirements are not yet known.

All process options can be combined with phosphorus removal if needed, but with an impact on the dimensioning.

The investment costs for all post treatment options are high, partially due to the excavation needed. The operational costs of all process options are high and AWT will significantly increase the cost of wastewater treatment.

A rough comparison of the benefits and problems of the process options, based on the CWPharma Guideline for Advanced API Removal[1], and applied for Viikinmäki WWTP considering the high bromide concentrations observed, space limitations and the current sludge usage, is presented in Table 13. All the processes described in Evaluating different AWT options were included but a complete evaluation including operational and investment costs has been made only for the process options where preliminary design was made.

*Table 13. Comparison of process options. 1. a) GAC filtration, 1 b) GAC filtration combined with P-removal, 2. a) PAC with deep bed filtration, 2. b) PAC with a contact tank and filter separation, 2. c) PAC addition in the activated sludge process, 3. a) Ozonation with MBBR, 3. b) Ozonation with sand or anthracite filter, 3 c) c) Ozonation prior to the current DN-filter and 4. Ozonation and GAC filtration*

| | 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 | +6 | | | +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.

The + and – values for the process options chosen for preliminary design, where also estimates of investment and operational costs were available, were summed up for an overview, but it should be noted that not all criteria have an equal importance.

Process option 1 a) GAC filtration had the highest positive score in the comparison and no potential barriers were recognised (Table 13). However, if the future requirements for API removal include high reductions for compounds that are not removed by activated carbon, the options must be reconsidered.

# References

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10. Helsinki Region Environmental Services Authority HSY. *PAC retention by Microsieve. Piloting at Viikinmäki WWTP.* Part of the CWPharma project.
11. Helsinki Region Environmental Services Authority HSY. *PAC retention by Mecana pile cloth filter. Piloting at Viikinmäki WWTP.* Part of the CWPharma project.

The CWPharma project reports (1, 7, 10 and 11) can be found at:

https://www.cwpharma.fi/en-US/Publications

# Appendix: Effluent quality measurements in CWPharma 2

The effluent quality at Viikinmäki WWTP is analysed twice a week from flow-based 24 h composite samples. $NO_2$-N, soluble $COD_{Cr}$, DOC and bromide are not part of the analysis made regularly, and therefore a separate analysis campaign for CWPharma 2 was made in spring 2021, where. The values are presented Table 14, together with $BOD_{7ATU}$, $COD_{Cr}$, TOC and $NO_3$-N which are measured regularly.

*Table 14. Effluent data during the analysis campaign for CWPharma 2.*

| Sampling date | Flow m³/d | $BOD_{7ATU}$ mg/L | $COD_{Cr}$ mg/L | TOC mg/L | $NO_3$-N mg/L | $NO_2$-N mg/L | $COD_{Cr}$, sol mg/L | DOC mg/L | Br mg/L |
|---|---|---|---|---|---|---|---|---|---|
| 15.3.2021 | 324 616 | 4.2 | 37 | 15.5 | 1.5 | 0.06 | 35 | 14 | <1 |
| 17.3.2021 | 285 826 | 3.9 | 39 | 15.3 | 1.5 | 0.05 | 38 | 14 | <1 |
| 21.3.2021 | 275 625 | 3.7 | 43 | 16.8 | 1.1 | 0.06 | 26 | 15 | 2 |
| 29.3.2021 | 436 861 | 12.8 | 47 | 13.5 | 2.9 | 0.17 | 28 | 12 | 2 |
| 6.4.2021 | 419 314 | 4.2 | 34 | 14.5 | 2.0 | 0.09 | 41 | 12 | 2 |
| 8.4.2021 | 358 547 | 4.0 | 44 | 15.0 | 1.8 | 0.07 | 50 | 12 | 2 |
| 11.4.2021 | 355 392 | 3.3 | 33 | 14.6 | 2.2 | 0.07 | 32 | 13 | 3 |
| 19.4.2021 | 278 570 | 3.1 | 32 | 15.3 | 2.2 | 0.04 | 31 | 14 | 1 |
| 22.4.2021 | 278 417 | 3.5 | 40 | 18.9 | 1.2 | 0.05 | 40 | 17 | 1 |
| 26.4.2021 | 325 030 | 3.4 | 36 | 14.0 | 1.9 | 0.06 | 36 | 12 | <1 |
| 3.5.2021 | 264 408 | 5.0 | 37 | 14.8 | 1.8 | 0.06 | 37 | 13 | <1 |
| 9.5.2021 | 254 956 | 4.1 | 38 | 14.6 | 1.5 | 0.06 | 36 | 14 | <1 |
| 13.5.2021 | 238 595 | 4.8 | 41 | 15.0 | 1.6 | 0.06 | 41 | 12 | 1.3 |
| 18.5.2021 | 269 479 | 5.1 | 29 | 15.1 | 1.9 | 0.10 | 29 | 14 | <1 |
| 20.5.2021 | 295 300 | 5.3 | 43 | 17.2 | 1.6 | 0.14 | 43 | 14 | <1 |
| 24.5.2021 | 286 195 | 4.3 | 33 | 14.7 | 1.9 | 0.06 | 33 | 12 | <1 |

37 APIs were analysed by Aarhus University from two 24 h flow-based composite samples and they are presented in Tables 15 and 16. The main usages are included in Table 16. The flow in 30.5.2021 (#1) was 322 000 m³/d and in 8.6.2021 (#2) 256 000 m³/d, meaning that there was some rainwater in the first sampling day. It can be seen, that all API results are somewhat higher in the second sample. (Figure 5)

In some API the difference in concentration was much higher than can be explained by rainwater (Figure 5). The first sampling day was Sunday and it can be seen that for example the use of the X-ray contrasting agents iohexol and iomeprol, is higher during workdays.

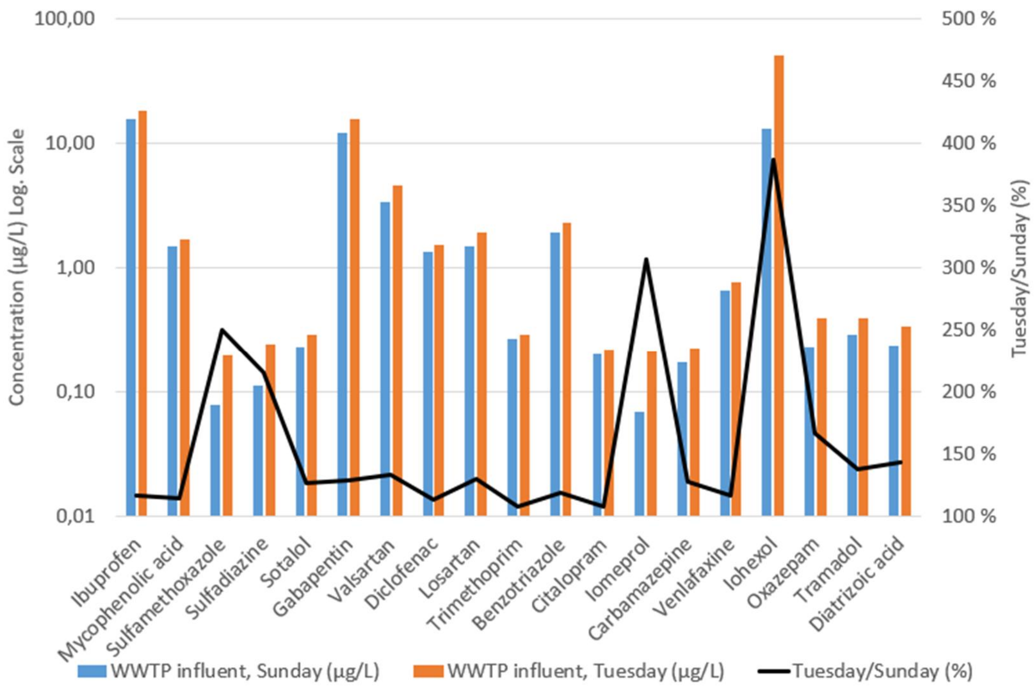


*Figure 5. APIs with Influent C>3*LCQ, Sunday vs. Tuesday*

The reduction or transformation ("change") is presented in Figure 6. It should be noted that the influent and effluent samples were collected at the same time and thus, the Sunday effluent sample is equivalent to the Saturday influent sample, which may be the reason for some of the observed negative changes (increase of concentration) in the Sunday samples.

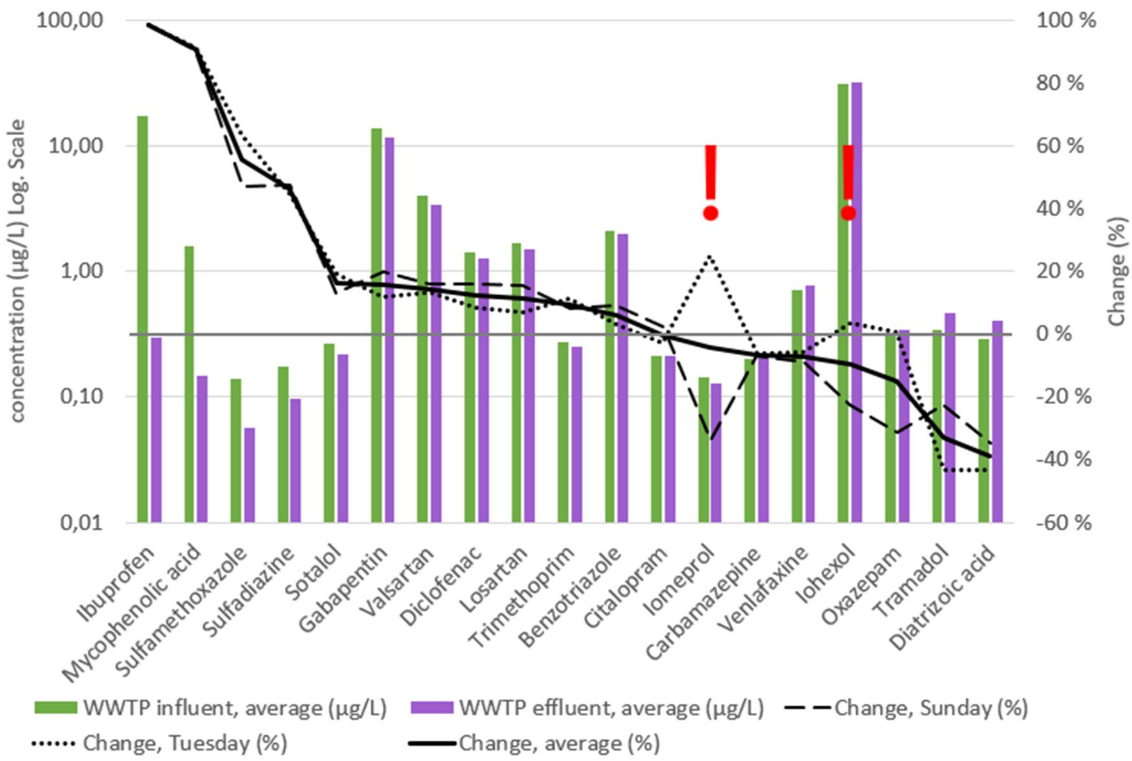


*Figure 6. APIs with Influent C>3*LCQ, influent vs. effluent*

*Table 15. API results from sampling dates 30.5.2021 (#1) and 8.6.2021 (#2). Analyses made by Aarhus University.*

| API | LOQ | Unit | WWTP Influent | | | WWTP Effluent | | | Change | | | Influent C ≥ 3 *LOQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (#1) | (#2) | (avg) | (#1) | (#2) | (avg) | (#1) | (#2) | (avg) | |
| Atenolol | 0.05 | [µg/L] | 0.13 | 0.15 | 0.14 | 0.07 | 0.09 | 0.08 | 46 % | 44 % | 45 % | 0 |
| Azithromycin | 1 | [µg/L] | <1 | <1 | <1 | <1 | <1 | <1 | | | NA | 0 |
| Benzotriazole | 0.1 | [µg/L] | 1.91 | 2.27 | 2.09 | 1.73 | 2.20 | 1.97 | 9 % | 3 % | 6 % | 1 |
| Candesartan | 0.1 | [µg/L] | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | | | NA | 0 |
| Carbamazepine | 0.05 | [µg/L] | 0.18 | 0.22 | 0.20 | 0.19 | 0.24 | 0.21 | -7 % | -6 % | -7 % | 1 |
| Ciprofloxacin | 3 | [µg/L] | <3 | <3 | <3 | <3 | <3 | <3 | | | NA | 0 |
| Citalopram | 0.05 | [µg/L] | 0.20 | 0.22 | 0.21 | 0.20 | 0.22 | 0.21 | 2 % | -3 % | 0 % | 1 |
| Clarithromycin | 0.025 | [µg/L] | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 3 % | -4 % | 0 % | 0 |
| Clindamycin | 0.3 | [µg/L] | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | | | NA | 0 |
| Diatrizoic acid | 0.025 | [µg/L] | 0.24 | 0.34 | 0.29 | 0.32 | 0.49 | 0.40 | -34 % | -43 % | -39 % | 1 |
| Diclofenac | 0.05 | [µg/L] | 1.34 | 1.52 | 1.43 | 1.13 | 1.39 | 1.26 | 16 % | 9 % | 12 % | 1 |
| Eprosartan | 1 | [µg/L] | 1.27 | 1.74 | 1.50 | 1.07 | 1.45 | 1.26 | 15 % | 16 % | 16 % | 0 |
| Erythromycin | 0.0125 | [µg/L] | 0.029 | 0.033 | 0.031 | 0.034 | 0.037 | 0.036 | -18 % | -13 % | -16 % | 0 |
| Gabapentin | 0.05 | [µg/L] | 12.11 | 15.68 | 13.89 | 9.70 | 13.85 | 11.77 | 20 % | 12 % | 16 % | 1 |
| Ibuprofen | 0.3 | [µg/L] | 15.63 | 18.33 | 16.98 | <0.3 | <0.3 | <0.3 | 98 % | 98 % | 98 % | 1 |
| Iohexol | 0.05 | [µg/L] | 12.88 | 49.70 | 31.29 | 15.80 | 47.95 | 31.88 | -23 % | 4 % | -10 % | 1 |
| Iomeprol | 0.025 | [µg/L] | 0.07 | 0.21 | 0.14 | 0.09 | 0.16 | 0.13 | -34 % | 25 % | -4 % | 1 |
| Iopamidol | 0.05 | [µg/L] | 0.06 | <0.05 | ~ LOQ | <0.05 | <0.05 | <0.05 | 10 % | | 10 % | 0 |
| Iopromide | 0.05 | [µg/L] | <0.05 | 0.05 | ~ LOQ | <0.05 | 0.05 | ~ LOQ | | 6 % | 6 % | 0 |
| Irbesartan | 0.0125 | [µg/L] | <0.0125 | <0.0125 | <0.0125 | <0.0125 | <0.0125 | <0.0125 | | | NA | 0 |
| Losartan | 0.025 | [µg/L] | 1.47 | 1.91 | 1.69 | 1.24 | 1.78 | 1.51 | 16 % | 7 % | 11 % | 1 |
| Metoprolol | 0.1 | [µg/L] | 0.26 | 0.31 | 0.28 | 0.27 | 0.44 | 0.35 | -5 % | -45 % | -25 % | 0 |
| Mycophenolic acid | 0.05 | [µg/L] | 1.49 | 1.71 | 1.60 | 0.14 | 0.15 | 0.15 | 90 % | 91 % | 91 % | 1 |
| Olmesartan | 0.1 | [µg/L] | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | | | NA | 0 |
| Oxazepam | 0.05 | [µg/L] | 0.23 | 0.39 | 0.31 | 0.31 | 0.39 | 0.35 | -31 % | 1 % | -15 % | 1 |
| Phenazone | 0.3 | [µg/L] | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | | | NA | 0 |
| Propranolol | 0.05 | [µg/L] | 0.09 | 0.10 | 0.09 | 0.11 | 0.14 | 0.12 | -24 % | -42 % | -33 % | 0 |
| Roxithromycin | 1 | [µg/L] | <1 | <1 | <1 | <1 | <1 | <1 | | | NA | 0 |
| Sotalol | 0.025 | [µg/L] | 0.23 | 0.29 | 0.26 | 0.20 | 0.24 | 0.22 | 13 % | 19 % | 16 % | 1 |
| Sulfadiazine | 0.05 | [µg/L] | 0.11 | 0.24 | 0.18 | 0.06 | 0.13 | 0.10 | 47 % | 45 % | 46 % | 1 |
| Sulfamethizole | 0.1 | [µg/L] | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | | | NA | 0 |
| Sulfamethoxazole | 0.025 | [µg/L] | 0.08 | 0.20 | 0.14 | 0.04 | 0.07 | 0.06 | 47 % | 64 % | 55 % | 1 |
| Tramadol | 0.0125 | [µg/L] | 0.29 | 0.40 | 0.34 | 0.35 | 0.57 | 0.46 | -23 % | -43 % | -33 % | 1 |
| Trimethoprim | 0.0125 | [µg/L] | 0.27 | 0.29 | 0.28 | 0.24 | 0.26 | 0.25 | 8 % | 11 % | 10 % | 1 |
| Valsartan | 0.1 | [µg/L] | 3.39 | 4.53 | 3.96 | 2.86 | 3.93 | 3.40 | 16 % | 13 % | 14 % | 1 |
| Venlafaxine | 0.05 | [µg/L] | 0.65 | 0.77 | 0.71 | 0.71 | 0.81 | 0.76 | -9 % | -6 % | -7 % | 1 |

The results from the sample taken for the Fitness check module are included in Table 16. This sample (#3) was post-sedimented wastewater, whose API concentrations can be considered equivalent to WWTP effluent. The sample was collected from Monday morning to Tuesday morning. The results are quite similar to samples #1 and #2. Taking into consideration that the equivalent influent sample would have been collected from Sunday morning to Monday morning, the effect of weekend can be seen in the lower concentrations of the X-ray contrasting agents iohexol and iomeprol compared to the Tuesday sample (#2). The influent flow was 320 000 $m^3/d$.

*Table 16. API results from sampling dates 30.5.2021 (#1) and 8.6.2021 (#2) and the Fitness check sampling results from 7.6.2021 (#3). Analyses made by Aarhus University.*

| API | LOQ | Unit | WWTP Effluent | | | Main usage |
|---|---|---|---|---|---|---|
| | | | (#1) | (#2) | (#3) | |
| Atenolol | 0.05 | [µg/L] | 0.07 | 0.09 | 0.07 | Antihypertensives |
| Azithromycin | 1 | [µg/L] | <1 | <1 | <1 | Antibiotics |
| Benzotriazole | 0.1 | [µg/L] | 1.73 | 2.20 | 1.51 | Others |
| Candesartan | 0.1 | [µg/L] | <0.1 | <0.1 | <0.1 | Antihypertensives |
| Carbamazepine | 0.05 | [µg/L] | 0.19 | 0.24 | 0.25 | Anticonvulsants |
| Ciprofloxacin | 3 | [µg/L] | <3 | <3 | <3 | Antibiotics |
| Citalopram | 0.05 | [µg/L] | 0.20 | 0.22 | 0.23 | Antidepressants |
| Clarithromycin | 0.025 | [µg/L] | 0.07 | 0.07 | 0.07 | Antibiotics |
| Clindamycin | 0.3 | [µg/L] | <0.3 | <0.3 | <0.3 | Antibiotics |
| Diatrizoic acid | 0.025 | [µg/L] | 0.32 | 0.49 | 0.50 | X-ray contrast agent |
| Diclofenac | 0.05 | [µg/L] | 1.13 | 1.39 | 1.28 | NSAIDs and analgetics |
| Eprosartan | 1 | [µg/L] | 1.07 | 1.45 | 1.40 | Antihypertensives |
| Erythromycin | 0.0125 | [µg/L] | 0.034 | 0.037 | 0.03 | Antibiotics |
| Gabapentin | 0.05 | [µg/L] | 9.70 | 13.85 | 10.86 | Anticonvulsants |
| Ibuprofen | 0.3 | [µg/L] | <0.3 | <0.3 | 0.39 | NSAIDs and analgetics |
| Iohexol | 0.05 | [µg/L] | 15.80 | 47.95 | 16.03 | X-ray contrast agent |
| Iomeprol | 0.025 | [µg/L] | 0.09 | 0.16 | 0.06 | X-ray contrast agent |
| Iopamidol | 0.05 | [µg/L] | <0.05 | <0.05 | <0.05 | X-ray contrast agent |
| Iopromide | 0.05 | [µg/L] | <0.05 | 0.05 | <0.05 | X-ray contrast agent |
| Irbesartan | 0.0125 | [µg/L] | <0.0125 | <0.0125 | 0.01 | Antihypertensives |
| Losartan | 0.025 | [µg/L] | 1.24 | 1.78 | 1.52 | Antihypertensives |
| Metoprolol | 0.1 | [µg/L] | 0.27 | 0.44 | 0.29 | Antihypertensives |
| Mycophenolic acid | 0.05 | [µg/L] | 0.14 | 0.15 | 0.20 | Others |
| Olmesartan | 0.1 | [µg/L] | <0.1 | <0.1 | <0.1 | Antihypertensives |
| Oxazepam | 0.05 | [µg/L] | 0.31 | 0.39 | N/A | Psychopharmaceuticals |
| Phenazone | 0.3 | [µg/L] | <0.3 | <0.3 | <0.3 | Others |
| Propranolol | 0.05 | [µg/L] | 0.11 | 0.14 | 0.11 | Antihypertensives |
| Roxithromycin | 1 | [µg/L] | <1 | <1 | <1 | Antibiotics |
| Sotalol | 0.025 | [µg/L] | 0.20 | 0.24 | 0.24 | Others |
| Sulfadiazine | 0.05 | [µg/L] | 0.06 | 0.13 | 0.10 | Antibiotics |
| Sulfamethizole | 0.1 | [µg/L] | <0.1 | <0.1 | <0.1 | Antibiotics |
| Sulfamethoxazole | 0.025 | [µg/L] | 0.04 | 0.07 | 0.05 | Antibiotics |
| Tramadol | 0.0125 | [µg/L] | 0.35 | 0.57 | 0.40 | NSAIDs and analgetics |
| Trimethoprim | 0.0125 | [µg/L] | 0.24 | 0.26 | 0.22 | Antibiotics |
| Valsartan | 0.1 | [µg/L] | 2.86 | 3.93 | 2.99 | Antihypertensives |
| Venlafaxine | 0.05 | [µg/L] | 0.71 | 0.81 | 0.82 | Psychopharmaceuticals |