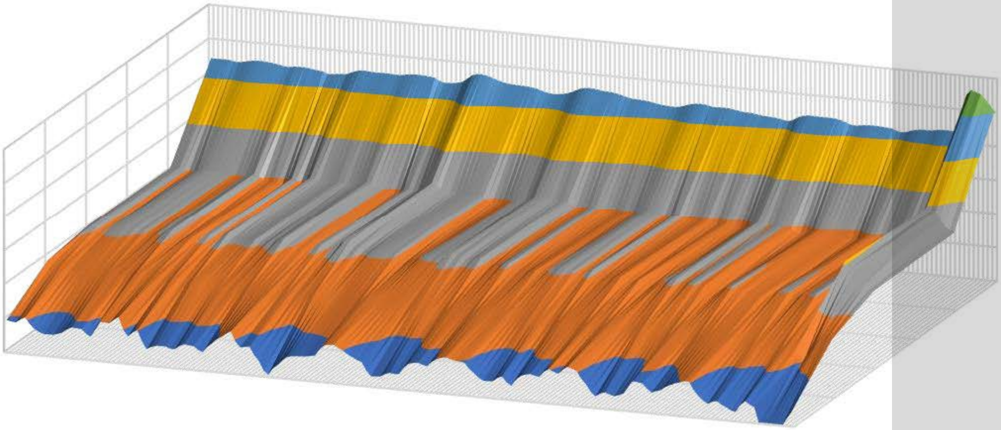
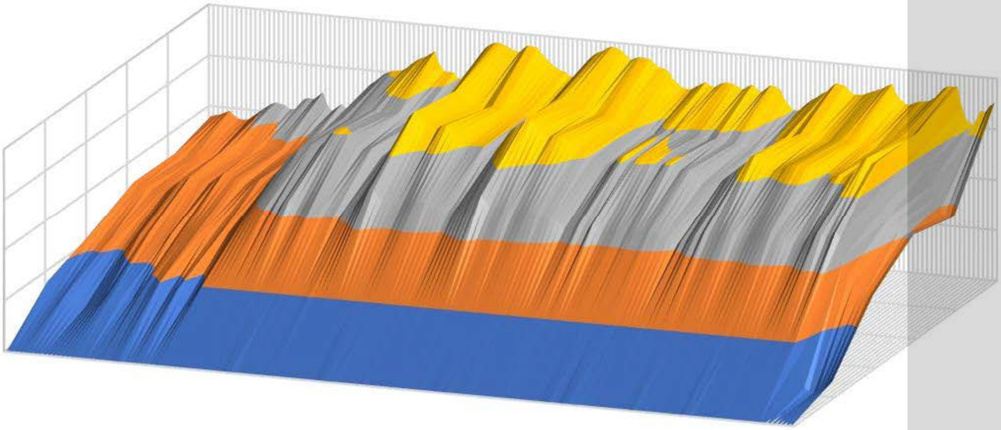
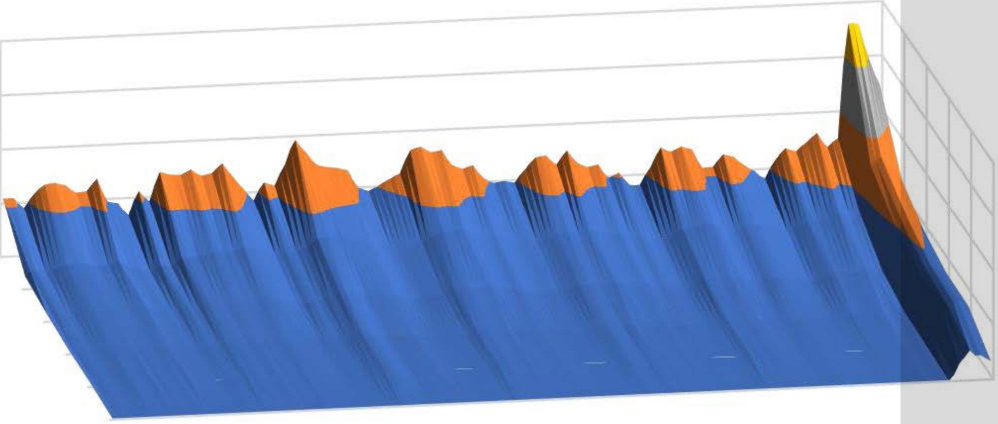
Zajednica izvršitelja

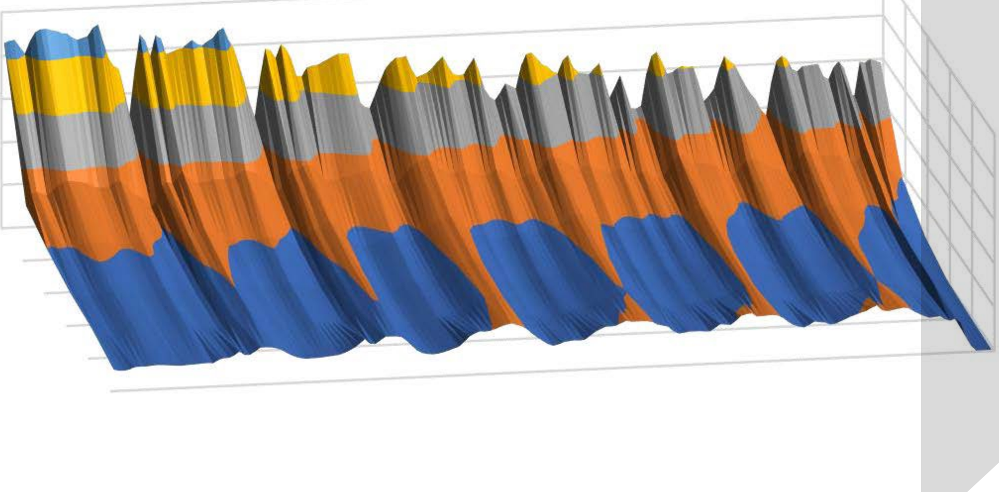
Naručitelj

Krajnji korisnik









STUDIJA OCJENE I PRAĆENJA UČINKOVITOSTI PROVEDBE PROJEKTA
IZGRADNJE KANALIZACIJSKE MREŽE I ANALIZA UČINKOVITOSTI RADA UREĐAJA
ZA PROČIŠĆAVANJE OTPADNIH VODA U GRADU POREČU – STUDIJA POREČ

IZVJEŠĆE 6d Dinamičko modeliranje UPOV-a - zimski i ljetni period: UPOV Vrsar

lipanj 2021

STUDIJA OCJENE I PRAĆENJA UČINKOVITOSTI PROVEDBE PROJEKTA IZGRADNJE KANALIZACIJSKE MREŽE I ANALIZA UČINKOVITOSTI RADA UREĐAJA ZA PROČIŠĆAVANJE OTPADNIH VODA U GRADU POREČU – **STUDIJA POREČ**

IZVJEŠĆE 6 – dio 4/4

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Zajednica izvršitelja

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IZVJEŠĆE 6 – dio 4/4

Dinamičko modeliranje UPOV-a - zimski i ljetni period: UPOV Vrsar

27. lipnja 2021

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23. lipnja 2021

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IHE Delft

United Nations
Educational, Scientific and
Cultural Organization
IHE
DELFT
Institute for
Water Education
under the auspices
of UNESCO

Evaluation and efficiency monitoring of the new implemented sewage network and wastewater treatment construction in the larger city of Poreč.

Report 6.4 - Dynamic modelling of wastewater treatment: Winter and summer conditions.

WWTP Vrsar

2021 07 15

Definitive Concept

innovative wastewater solutions

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Responsibility

Project Title	:	Evaluation and efficiency monitoring of the new implemented sewage network and wastewater treatment construction in the larger city of Poreč. Dynamic modelling the detailed design of WWTP Vrsar based on 2019 influent flow and concentration measurements under summer and winter conditions.
Working Title	:	Report 6.4 – WWTP Vrsar – Dynamic modelling of wastewater treatment: Winter and summer conditions.
Project Description:	:	Study of the environmental impact as the result of upgrading and operation of the wastewater system of the larger city of Poreč on coastal sea water quality. Integrated evaluation of the sewer system, wastewater treatment systems, coastal discharge, and sea water quality based on modelling tools.
Document number	:	ASM-20210715-RAP108
Status	:	Definitive Concept
Date	:	2021 07 15
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Content

1 Management summary

1.1 Introduction

The infrastructural investment “Sewerage and Wastewater Treatment Plants of City of Poreč”– Project Poreč, co-funded by European Union, is one of the largest investments in the public sector in Republic of Croatia. It involves rehabilitation and extension of the existing sewerage system and construction of four new wastewater treatment plants (WWTPs). The goal is to better protect the environment in and around the Poreč coastal area. Complementary a project is developed titled “Integrated Modelling of Wastewater Infrastructure System of City of Poreč” – Modelling Project. This project is an integrated environmental assessment to obtain a better understanding of the environmental impact of the system performance which is evaluated under range of operational conditions. A scenario study is developed using state-of-the-art (modelling) tools and methods which allows a holistic assessment of the wastewater system. The results of this study are in assistance of future operations and wastewater management in the region and used to elevate knowledge and professional skills of local water sector professionals.

The Modelling Project consists of 4 main components, namely:

- Part 1: Modelling the sewage collecting and transport system of City of Poreč,
- Part 2: Modelling of operation and performance of 4 WWTPs of City of Poreč,
- Part 3: Model assessment impact offshore outlets on aquatic water quality,
- Part 4: Establishment of the experimental laboratory setup for monitoring and optimization of wastewater management and operation.

Including a training is organized to extend the capacity of water professionals in the use of wastewater modelling for future assessments.

The Modelling project has a holistic system approach covering collection, processing, and aquatic discharge of wastewater, the interrelation between the different wastewater systems and impact on the environment, public health, and coastal seawater quality.

Several scenarios are calculated to explore the impact of Project Poreč on the previous mentioned factors and to and establish the best methods for management of the wastewater systems from an integrated perspective.

Modelling is used to demonstrate how upgrade of the Poreč wastewater system improves the environment. Further insight is developed in the overall interaction of the sub-systems on seawater quality. Knowledge is developed on how to operate and optimize the different wastewater systems, with the best overall results.

1.2 Project goals

The overall objective of the Poreč modelling project is to demonstrate how upgrading the total wastewater system improves the sea water quality in the Poreč costal region. Therefore, the total wastewater system is modelled consisting of several sub-systems. By modelling the WWTP under different (extreme) conditions it is investigated how effluent discharge load and quality will affect the sea water quality. For each studied scenario, effluent concentration and flow profiles are calculated. These data are subsequently used as input for sea water quality modelling from which the environmental impact is calculated.

The first report in this series is the inception report and static modelling of the detailed design. Relevant data for the WWTP modelling and scenario study is collected, organized, processes for modelling and a static model is reported. The methods used for this research are explained and a general planning is made for the execution of the work.

In this report, the static models are further developed towards dynamic models including dynamic aeration and process control. It is evaluated how the detailed design performs under realistic influent and operational conditions. The effluent quality of the dynamic simulations is used for further analysis and modelling of coastal seawater quality.

1.3 Reader

This report concerns Modelling project Part 2: Modelling of operation and performance of 4 WWTPs of City of Poreč. Each WWTP is modelled and reported separately. Modelling project Part 2 is developed in four steps, one report per step for each individual WWTP.

- Step 1: Static WWTP modeling based on the detailed design. In the total project this is report number 5, consisting of 4 sub-reports one for each WWTP (report number 5.1 to 5.4).
- Step 2: Dynamic WWTP modeling based on dynamic winter and summer influent measurements. In the total project this is report number 6, consisting of 4 sub-reports one for each WWTP (report number 6.1 to 6.4).
- Step 3: Analysis of operational WWTP scenarios. This report takes the results of the previous studies, and a series of operational scenarios are developed and quantified on the coastal discharge loads and concentrations (report number 7).
- Step 4: Model validation based on operational measurements. In the total project this is report number 8, consisting of 4 sub-reports one for each WWTP (report number 8.1 to 8.4).

This sub-report presents the dynamic modelling of WWTP Poreč-North. The data for this study were measured in the winter and summer of 2019. One week in each season, during 7-days 24-hours, per WWTP location 84 samples are collected in the untreated sewage. In each sample we measured 16 wastewater parameters including flow (chapter 4), concentrations (chapter 5) and loads (chapter 6). The dynamic model is developed from detailed designs and based on the static model developed in the previous Step 1 report (chapter 3) Actual process control and the daily process operation is modelled under realistic influent conditions. This includes daily operation of dewatering, rain events and concentration peak loadings originating from touristic, agricultural, or industrial activity.

The results for winter and summer are presented in chapters 7 and 8. The results are presented in a series of graphs per modelled season.

The study is concluded in chapter 9. For each season it is shown that the treatment plants can treat wastewater to the desired level and have sufficient flexibility to cope with different wastewater conditions. The effluent results of this study are used as an indication for the coastal discharge loads and concentrations over time. These data are used for scenario development in Step 3 and sea water quality modelling.

1.4 General conclusions

- All measurement and modelling data is collected and organized and made available in spreadsheets. The data is processed and effectively presented in this report in figures and graphs from which simulations can be reproduced.
- The detailed design is simulated under realistic dynamic influent and operational conditions. From these results it is concluded that the design meets the effluent requirements.
- For each season it is shown that the treatment plant can treat wastewater to the desired level and has sufficient flexibility to cope with different wastewater conditions.
- The effluent results are determined by the method of operation and the applied process control. This research shows that it is possible to effectively control the plant using simple however realistic process control.
- The effluent discharge can be met under all modelled conditions. This included rain events (during the winter conditions) and several concentration peak loads during both the measurement periods.
- The study shows that the designs have enough operational flexibility to be operated effectively under very different winter and summer conditions.
- Winter operation meets the requirements, however, the required operation not typical in respect to a very high SRT, very long anaerobic and anoxic HRT, very high internal recycle rates proportional to the influent and high DO in the activated sludge system.
- Specific point of attention for (winter) operation are:
    - Application of hydraulic and sludge residence time that are very long.
    - $CO2$ stripping in the aeration and MBR caused by over aeration, a drop in alkalinity and potentially the pH.
    - Too low internal recycles causing long anaerobic zones and increased decay of biomass, degeneration of nitrification capacity and degraded Bio-P.
    - P-release in the WAS storage tank with HRT more than 2-3 hours.
    - Too little WAS sludge production (long SRT) to meet the Bio-P requirement.
- Summer operation is a classical type of operation within the typical operational range. Dynamic simulations indicate that under summer peak loading the aeration capacity and aerobic SRT can become limiting. On average however, all is within the designed range.
- The dynamic simulation study is successfully completed, and the results can be used for further development of the scenario study and sea water quality modelling.

1.5 Main recommendation

It is recommended to proceed with further development of the scenario analysis and sea water modelling taking in account the presented conclusions.

2 Introduction

This project is an integrated environmental assessment to obtain a better understanding of the environmental impact of the system performance which is evaluated under range of operational conditions. The four WWTPs of City of Poreč are modelled each based on their detailed design and measured influent flows and concentrations in the summer and winter of 2019. This is done statically based on average values and dynamically to validate the operation under more realistic dynamic conditions and make predictions of the effluent discharge and quality. In a scenario study, these data are used to assess the impact of the new wastewater facilities on the costal seawater quality. Several scenarios are developed to explore the impact of Project Poreč and to and establish the best methods for management of the wastewater systems from an integrated perspective. Modelling is used to demonstrate how upgrade of the Poreč wastewater system improves the environment. Further insight is developed in the overall interaction of the sub-systems on seawater quality. Knowledge is developed on how to operate and optimize the different wastewater systems, with the best overall results.

In the previous report, WWTP modelling methods are presented and a static model is developed based on the detailed design. Therefore, relevant data is collected, processed, and presented for modelling. This is done according to a modelling protocol, which also is introduced in the first part of this study.

Information is gathered from detailed plant design reports. The volume, quality and time distribution of sewage is established from field measurements in each of the 4 collecting sewar systems. This is done under high loading summer conditions and low loading winter conditions. This data is processes and visualized and used to develop the WWTP model. The model is developed from a static model towards a dynamic by including time series, actual operational conditions, and realistic process control. The model is simulated over 7 days for both measurement periods calculating summer and winter conditions.

This report presents actual measured data and modelled data. For measured data, graphs with a white background are used. Dynamic modelled data is presented in graphs with a light-yellow background.

2.1 Reader

This report concerns Modelling project Part 2: Modelling of operation and performance of 4 WWTPs of City of Poreč. Each WWTP is modelled and reported separately. Modelling project Part 2 is developed in four steps, one report per step for each individual WWTP.

- Step 1: Static WWTP modeling based on the detailed design. In the total project this is report number 5, consisting of 4 sub-reports one for each WWTP (report number 5.1 to 5.4).
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The study is concluded in chapter 9. For each season it is shown that the treatment plants can treat wastewater to the desired level and have sufficient flexibility to cope with different wastewater conditions. The effluent results of this study are used as an indication for the coastal discharge loads and concentrations over time. These data are used for scenario development in Step 3 and sea water quality modelling.

3 Dynamic modelling of WWTP Vrsar

3.1 Introduction

The dynamic model is developed from the static model presented in Step 1 of this research. Model details are presented in the appendix of report Step 1 (series numbered 5.1 to 5.4). Design conditions are adapted from the original detailed design documentation which is also presented in the previous report.

To accommodate dynamic calculations, some assumptions and adjustments need to be made. Not all details for dynamic modelling are available in the design information. To fill this information expert judgement is used. None of the applied assumptions, are critical for the modelling results.

For each model, two 7-day calculations are performed, winter and summer. The 24-hour 7-day dynamic influent measurements are used to calculate the performance of each design dynamically under realistic operational conditions.

During summer high season, all parallel lanes of all WWTPs are in operation. During the winter low season, the wastewater quantity is much smaller. To accommodate these conditions parallel lanes can be taken out of operation. In the models this is indicated by dashed lines. When lines are out of operation no inflow, recycle and aeration is applied to the reactors. The treatment lines are standing idle and are not included in any calculation.

The models that are developed, for static and dynamic, winter and summer simulations, are all identical regarding the detailed design they are based on and BioWin model parameter settings which are all on default settings (no specific calibration was used nor required to simulate the plants). However, the models are different regarding the influent concentration (static or dynamic, summer and winter), wastewater specification parameter settings, process control settings, recycle, aeration, and the amount of parallel lines and MBRs in operation. Especially the applied process control makes a large difference between static and dynamic models. More about the operational differences is explained in the next sections.

3.2 Methodology

The dynamic modelling is based on the previous developed static model of the design of WWTP Poreč-North. Dynamic flow and concentration profiles are used as model input. The influent concentration measurements applied in the model are total COD, total phosphorus, TKN and ISS. Of these 4 influent parameters, the model calculates all the other influent parameters under which soluble and non-soluble fractions. This is done based on the influent specification which is performed in Step 1 of this report series. The

24-hour measured pH is also used as a direct model input. Other influent parameters that are required as model input are Calcium and Magnesium. These values are assumed to be constant, and the concentration is estimated from drinking water quality measurements. Winter conditions are simulated with a constant temperature of 12 °C. Summer simulations with 20 °C.

Application of process control strongly affects the process and effluent results. For demonstration, a simple control strategy is modelled that also could be applied in practice. This strategy is used for all 4 WWTPs making it possible to compare the operations. For winter and summer conditions the operational settings and control settings are changed to accommodate full nitrification and P-removal.

3.3 Process control applications

The following dynamic process controllers are used:

- Aeration control of the first aerated tank (AT-A)
- Aeration control of the second aerated tank (AT-B)
- Control of the anoxic recycle (ANOX-R).
- Control of Iron dosage for P-removal (FECL3)
- Control of polymer dose (PE) for dewatering.
- Control of the WAS flow and related dewatering.
- Control of the return sludge recycle from the MBR.

The BioWin controller application is used for control of Air input of AT-A, the anoxic recycle, polymer and iron dosage. The controls can be adjusted for summer and winter conditions. Other controls are standard BioWin options like table controls (the WAS pump), proportional control (return flow, grit, and screening) and aeration control.

To model aeration in AT-A and AT-B, aeration parameters are used from the detailed design. Therefore, the type and amount of diffusers is modelled, the tank dimensions, installation diffuser height from the bottom of the tank, bubble rise height and maximum water level, maximum installed air flow capacity, maximum air flow per diffuser, surface per diffuser and the water temperature. For the second aeration tank (AT-B) the model controls DO on 2,0 mgO2/L based on the air flow of AT-B. For the first aeration tank (AT-A) the air flow is controlled using a 3-step table control which switches the air input of AT-A based on measurement of NH4 in the outflow of the aeration. Alternative control under winter conditions of AT-A is using a DO setpoint or shutting of the aeration of AT-A completely.

3.4 Other model assumptions

- Under low loading conditions during the winter period, the plant loading can become very low compared to the available reactor volumes. This can result in very long SRT and HRT which can negatively affects nitrification and bio-P. Very long anaerobic HRT causes anaerobic decay of otherwise active biomass. To minimize this effect the designs, can apply a high internal recycle thereby reducing the effect of anaerobic residence time and decay of biomass.

- In all simulations the volume of the WAS storage is very high relative to the WAS production. Storage longer that 2-3 hours results in P-release from the Bio-P sludge. This is recycled via the dewatering to the activated sludge resulting in increased effluent phosphate. To avoid P-release in the WAS tank in the model the volume is reduced resulting in a hydraulic residence time shorter than 2-3 hours. The WAS tank should not be used for storage of activated sludge and only filled when the dewatering is in operation.
- Dewatered sludge is produced 10 hours of each day. Dewatered sludge is set to approximately 23% dry matter according to the design. The solids removal efficiency is set to 97%. Solids in the centrate return to the waterline via an internal drainage.
- Grit removal and screening is estimated according to the design as a percentage relative to the influent flow. The dry mass fraction of grit and screening is unknown and an estimated value, generally higher than dewatered sludge.
- It is assumed grit and screening is stored separately from the secondary sludge production. A dry weight / volume for the compacted material is unknown and assumed.
- The MLSS return sludge recycle from the MBR reactors is assumed proportional the influent according to the designed recycle factor (factor to influent of 500%). This results in a relative stable TSS concentration in the activated sludge tanks and sludge production.
- It is assumed that the MBR is fully aerated, and the airflow is not controlled during the summer. During the winter, the total aerated volume can become too high, resulting in stripping of CO2 and drop in alkalinity. Therefore, in some winter simulations, one or more MBR reactors are taken out of operation, or the maximum DO is set to 6 mgO2/l. MBR reactors out of operation are indicated by dashed lines.
- For the operation of the MBRs it is assumed that there is a trace of solids in the effluent as well as a trace of colloidal materials. Therefore, solids removal of the membranes is set to remove 99,9% of solids and 99,99% of colloidal materials. These effluent concentrations may be used to represent viruses and facial bacteria for further sea water modeling.
- Effluent is assumed to be fed continuously to the effluent storage tank which has an overflow. The storage therefore acts as an effluent buffer which especially in winter and low flow conditions has a strong effect on reducing effluent fluctuations over the day.

4 Influent flow measurements

4.1 Introduction and Methods

The influent flow is measured continuously for 7 days, 24-hours, with measurement points produced every 2 hours based on a collected flow sample. Raw sewage is measured for all 4 treatment locations. For the winter period, the measurements are from Monday 21-01-2019 9:00 till Monday 28-01-2019 7:00. For the summer period, the measurements are from Friday 19-07-2019 9:00 till Friday 26-07-2019 7:00.

For dynamic modelling, the total measured flow profile is used including rain and peak loading events. During the winter measurements, a large rain event occurred on 28-1-2019. This event is included in the simulations and effects the effluent results. During the summer, no rain event occurred. From the total time measurement series excluding the rain event an hourly average profile is calculated for both summer and winter conditions. This profile indicates the wastewater flow expected at each hour of the day. This data is used to reconstruct missing datapoints in the flow measurements.

4.2 Winter influent flow measurement results

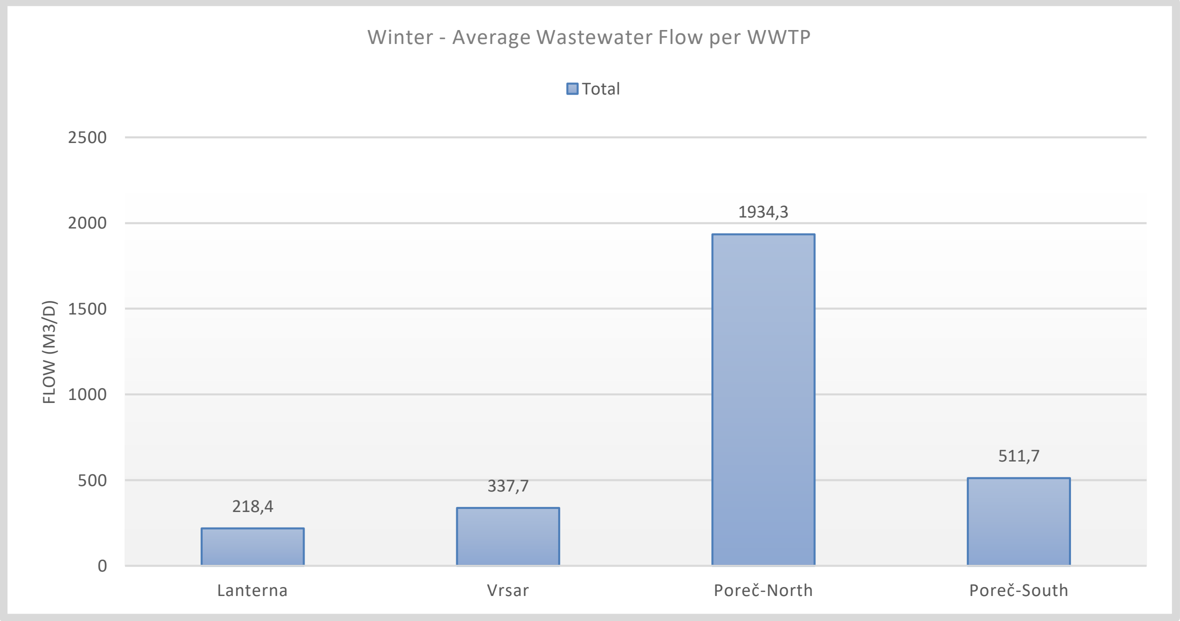


Figure 1. Winter - Average Dry Weather Wastewater Flow per WWTP. Based on the year 2019, 24-hour 7-day measurements.

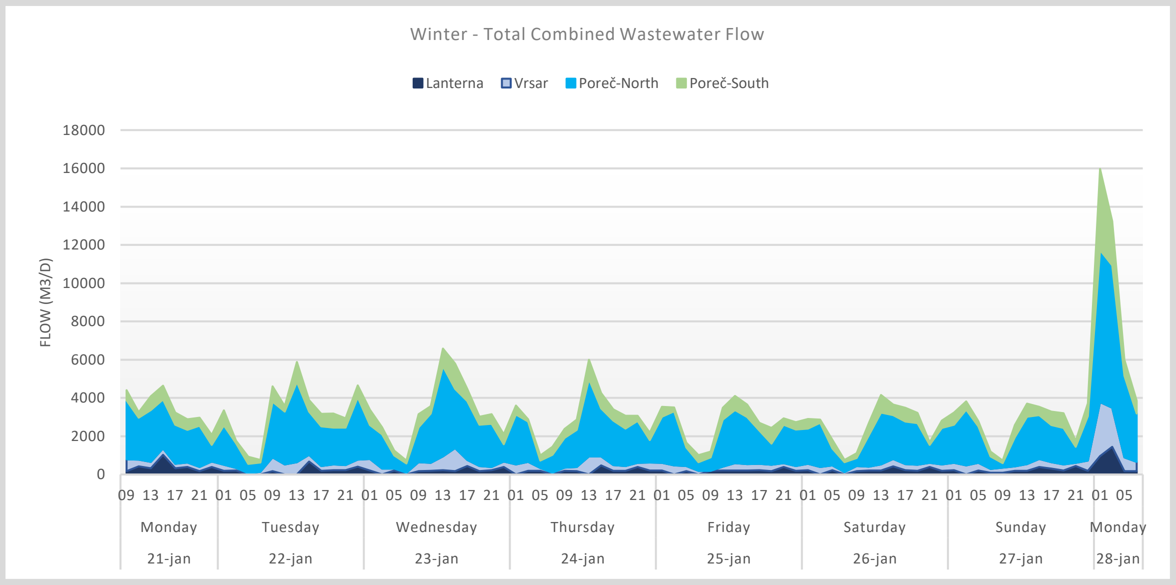


Figure 2. Winter - Total Combined Wastewater Flow of all WWTP’s.

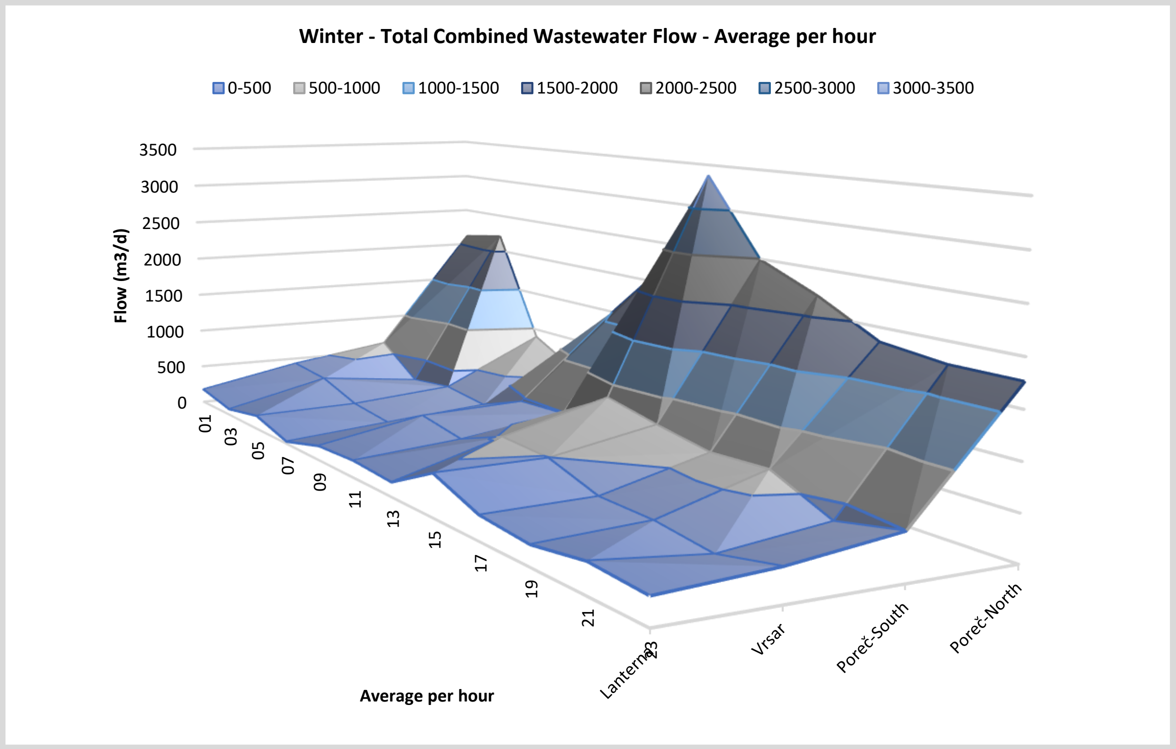


Figure 3. Winter – Surface plot Dry weather Total Combined Wastewater Flow 24-hour average hourly measurements. Excluding the rain event January 28th. The plot order is from lowest to highest wastewater producing community.

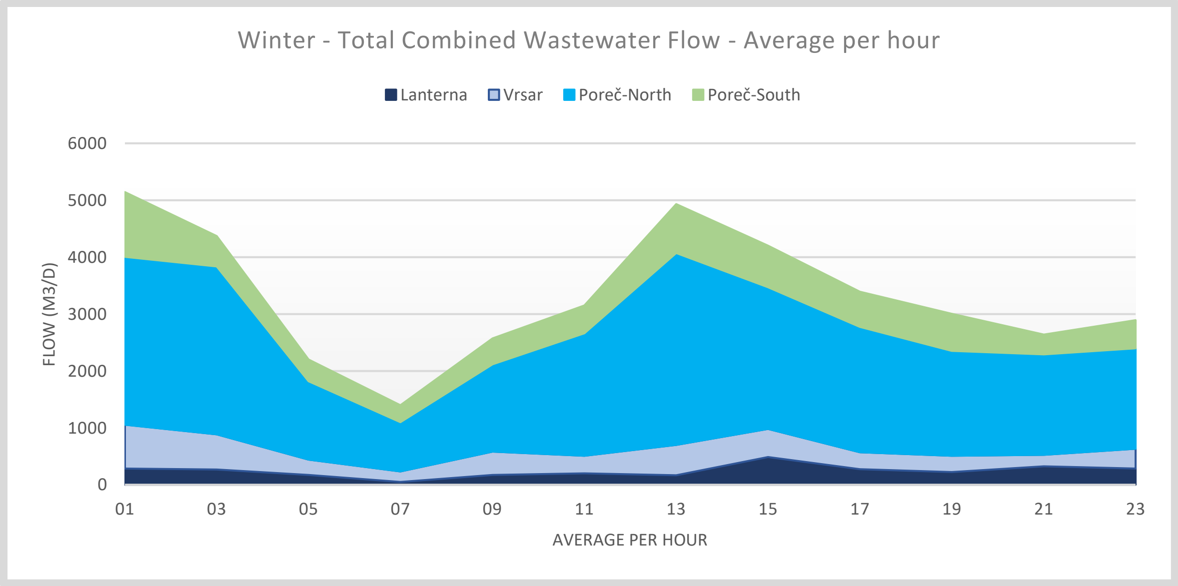


Figure 4. Winter – Mixed weather Total Combined Wastewater Flow 24-hour average hourly measurements. Including the rain event January 28th.

Table 1. Winter – Mixed weather Total Combined Wastewater Flow 24-hour average hourly measurements (in m3/d). Data includes the rain event measured January 28th.

Hour of the day	Lanterna	Vrsar	Poreč-North	Poreč-South	Average
01	286,3	769,7	2950,3	1136,6	1285,7
03	269,1	613,7	2952,0	533,1	1092,0
05	169,7	272,6	1376,6	382,3	550,3
07	48,0	185,1	865,7	298,3	349,3
09	171,4	408,0	1534,3	457,7	642,9
11	200,6	308,6	2151,4	486,9	786,9
13	166,3	531,4	3375,4	860,6	1233,4
15	483,4	497,1	2490,9	728,6	1050,0
17	270,9	300,0	2204,6	617,1	848,1
19	221,1	286,3	1846,3	648,0	750,4
21	322,3	202,3	1765,7	348,0	659,6
23	281,1	349,7	1764,0	497,1	723,0
Average	**240,9**	**393,7**	**2106,4**	**582,9**	**831,0**

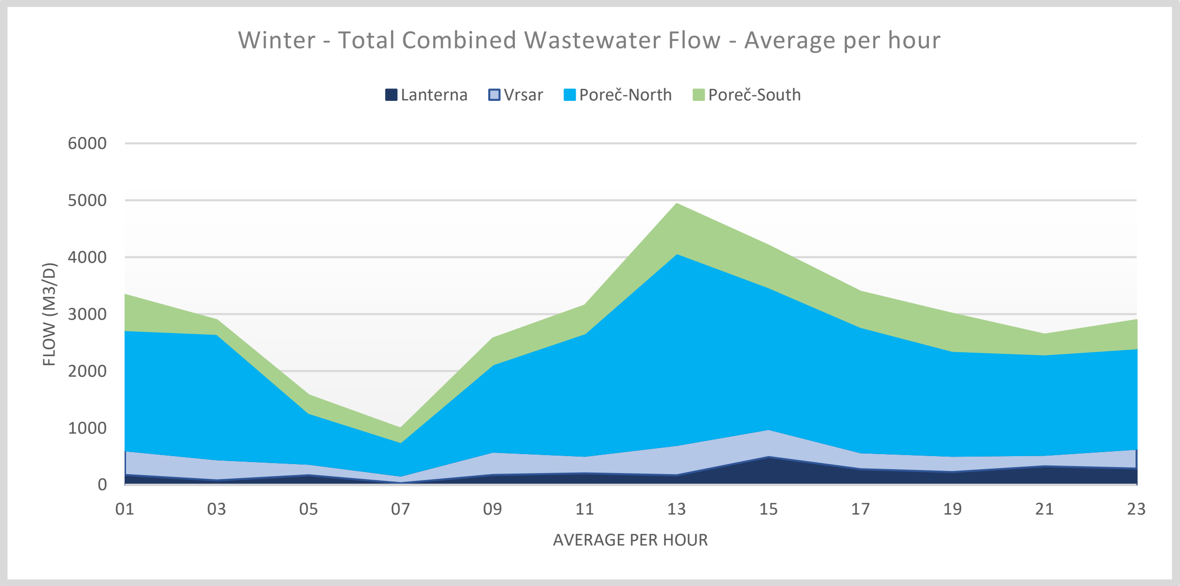


Figure 5. Winter – Dry weather Total Combined Wastewater Flow 24-hour average hourly measurements. Excluding the rain event January 28th. These data are used to reconstruct missing measurements in the flow data time series.

Table 2. Winter – Dry weather Total Combined Wastewater Flow 24-hour average hourly measurements (in m3/d). Data excludes the rain event measured January 28th. These data are used to reconstruct missing measurements in the flow data time series.

Hour of the day	Lanterna	Vrsar	Poreč-North	Poreč-South	Average
01	174,0	428,0	2116,0	620,0	834,5
03	74,0	374,0	2204,0	238,0	722,5
05	168,0	200,0	894,0	308,0	392,5
07	26,0	136,0	588,0	238,0	247,0
09	171,4	408,0	1534,3	457,7	642,9
11	200,6	308,6	2151,4	486,9	786,9
13	166,3	531,4	3375,4	860,6	1233,4
15	483,4	497,1	2490,9	728,6	1050,0
17	270,9	300,0	2204,6	617,1	848,1
19	221,1	286,3	1846,3	648,0	750,4
21	322,3	202,3	1765,7	348,0	659,6
23	281,1	349,7	1764,0	497,1	723,0
Grand Total	218,4	337,7	1934,3	511,7	750,5

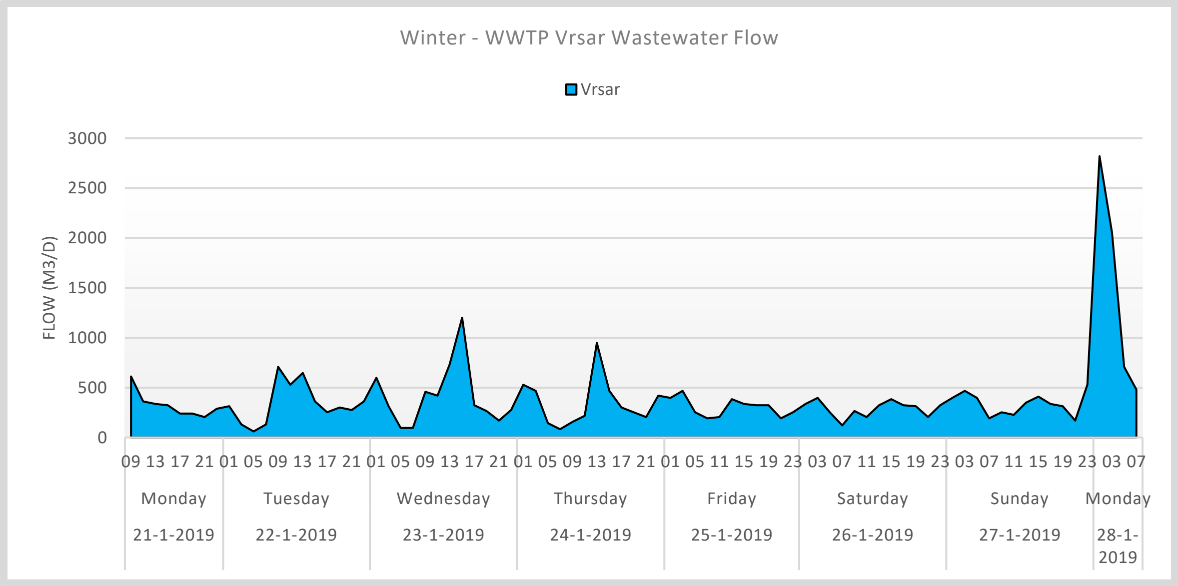


Figure 6. Winter - WWTP Vrsar Wastewater Flow 24-hour 7-day dynamic measurements. This data is used for dynamic modelling.

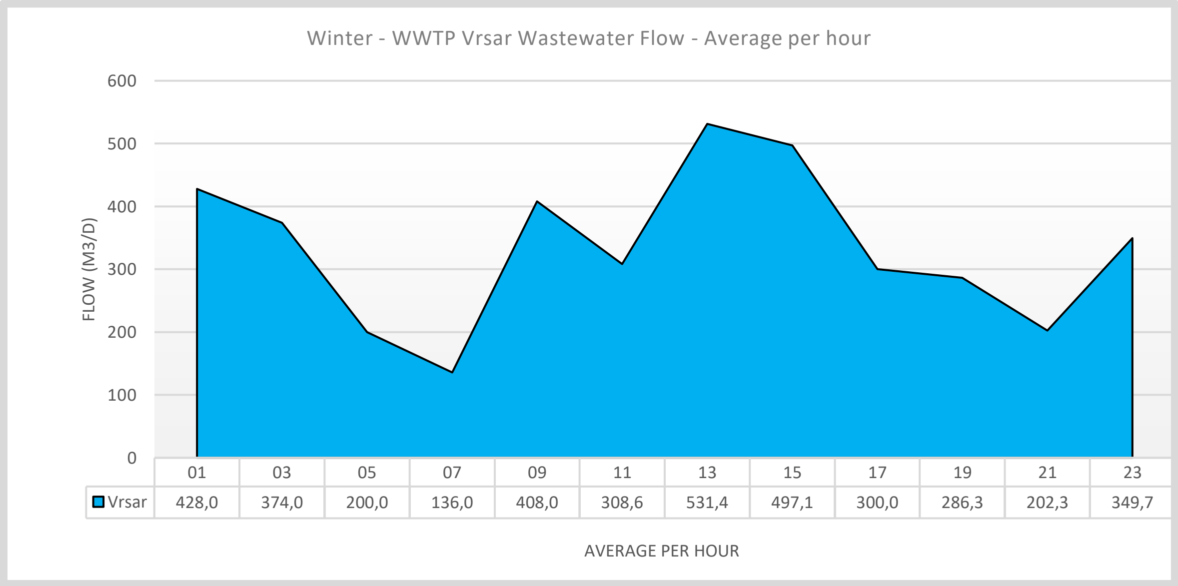


Figure 7. Winter - WWTP Vrsar Dry Weather Wastewater Flow 24-hour average hourly measurements. These data are used to reconstruct missing datapoints in the 7-day 24-hours measurements and can be used for scenario calculations.

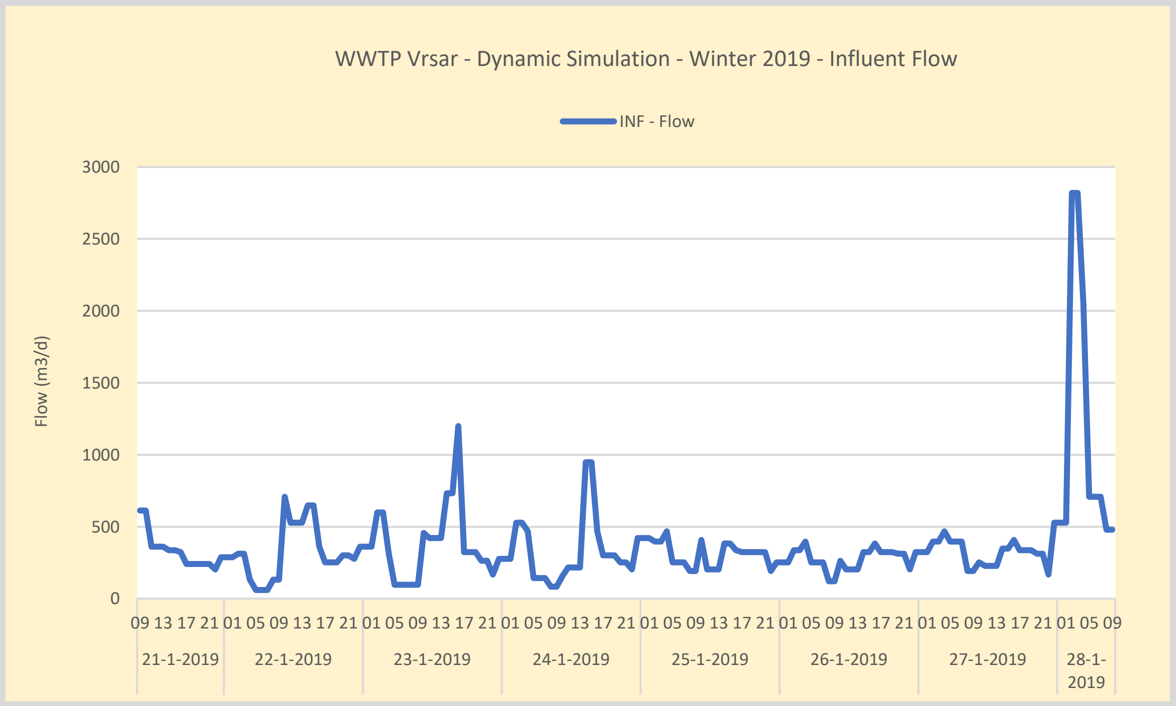


Figure 8. Winter – BioWin modelling WWTP Vrsar: Wastewater Flow 24-hour 7-day dynamic model input data. Some datapoint are reconstructed form 24-hour average hourly measurements. The data is interpolated in the model on an hourly basis.

4.3 Summer influent flow measurement results

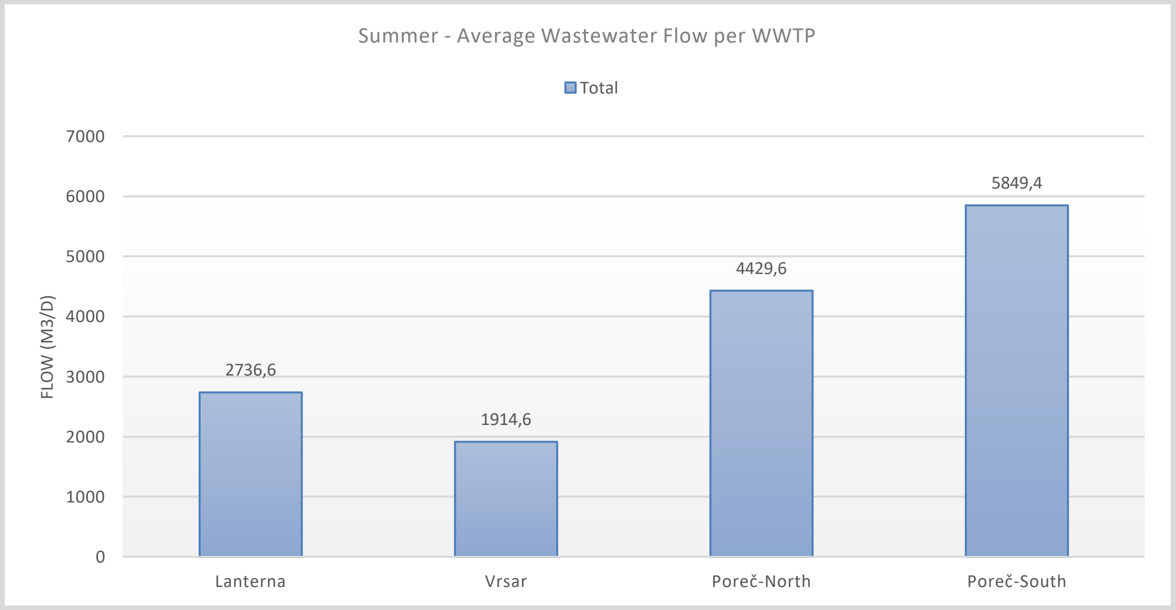


Figure 9. Summer - Average Wastewater Flow per WWTP. Based on the year 2019, 24-hour 7-day measurements.

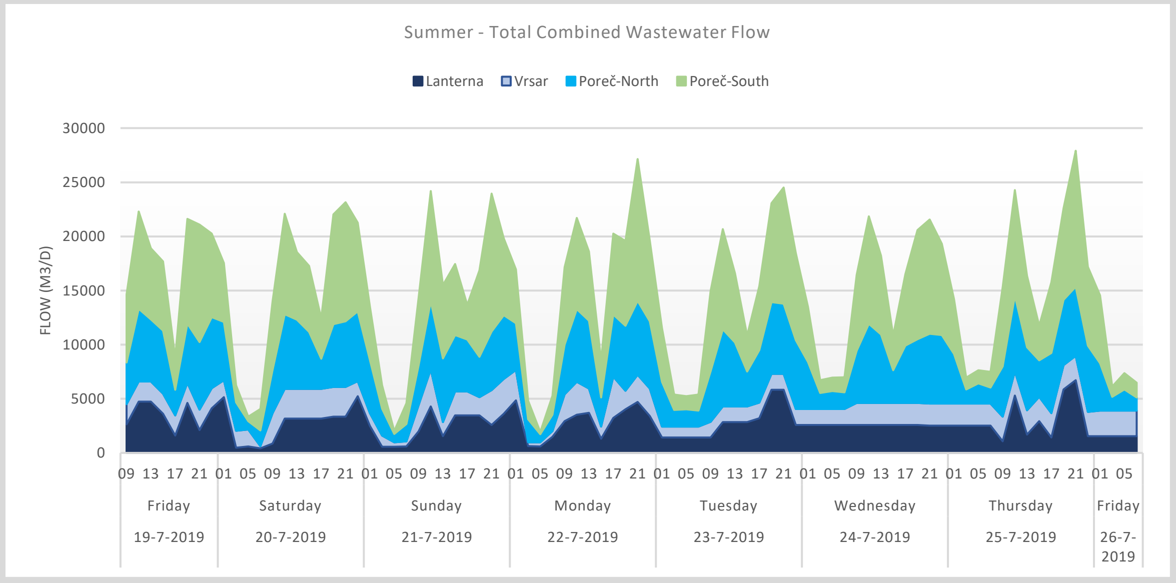


Figure 10. Summer - Total Combined Wastewater Flow 24-hour 7-day dynamic measurements. No rain event occurred during the measurement period.

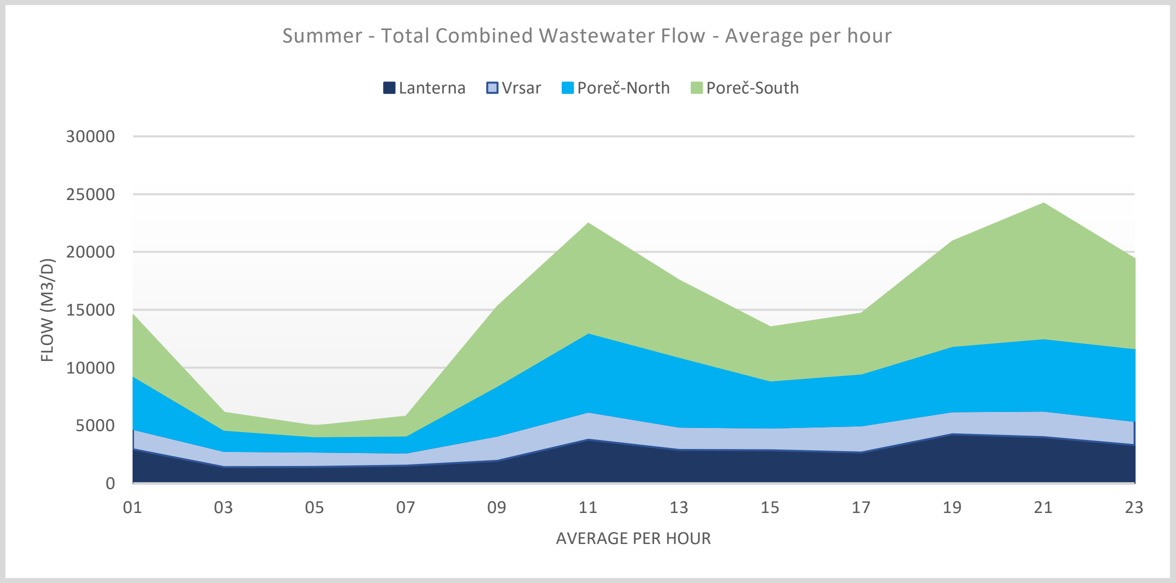


Figure 11. Summer - Total Combined Wastewater Flow 24-hour average hourly measurements. No rain event occurred during the measurement period.

Table 3. Summer –Total Combined Wastewater Flow 24-hour average hourly measurements (in m3/d). No rain event occurred during the measurements.

Hour of the day	Lanterna	Vrsar	Poreč-North	Poreč-South	Average
01	2936,6	1775,7	4580,6	5240,6	3633,3
03	1392,0	1403,7	1839,4	1441,7	1519,2
05	1404,0	1323,1	1332,0	869,1	1232,1
07	1508,6	1158,5	1460,6	1625,1	1438,2
09	1928,6	2192,6	4314,9	6817,7	3813,4
11	3773,1	2413,7	6855,4	9394,3	5609,1
13	2888,6	1998,9	6041,1	6600,0	4382,1
15	2838,9	1964,6	4080,0	4587,4	3367,7
17	2662,3	2352,0	4476,0	5187,4	3669,4
19	4242,9	1974,9	5646,9	9037,7	5225,6
21	3972,0	2307,4	6258,9	11648,6	6046,7
23	3291,4	2110,3	6269,1	7743,4	4853,6
Average	2736,6	1914,6	4429,6	5849,4	3732,5

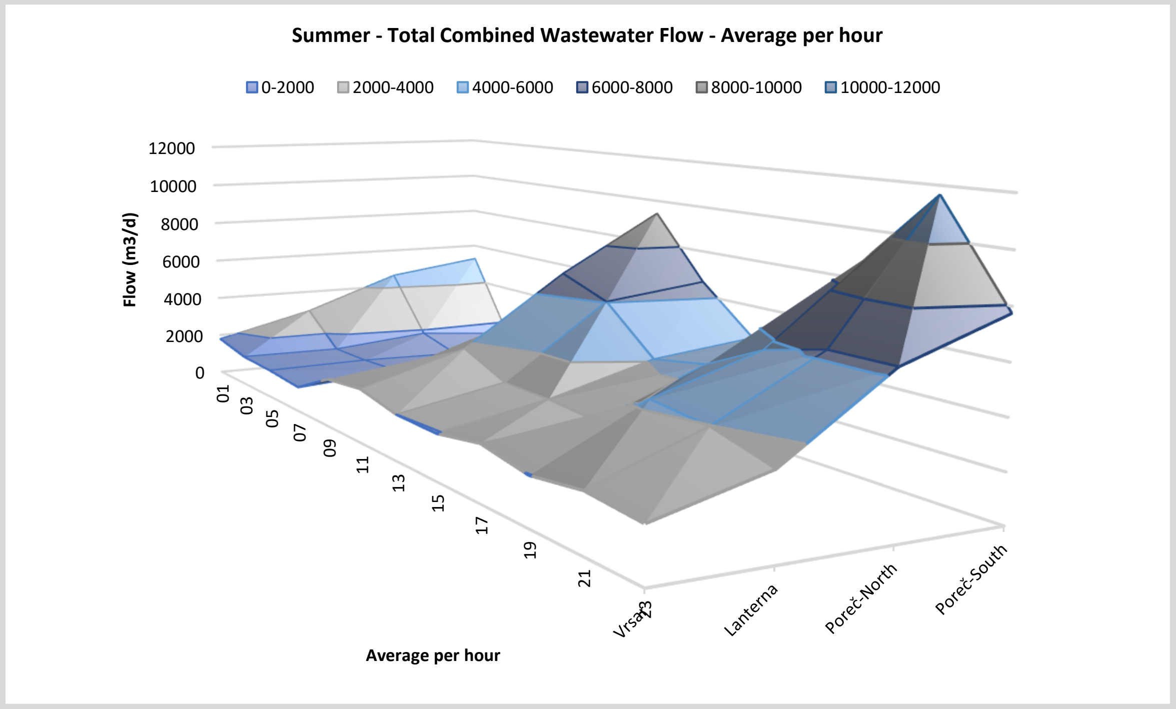


Figure 12. Summer – Surface plot Total Combined Wastewater Flow 24-hour average hourly measurements. No rain event occurred during the measurements. The plot order is from lowest to highest wastewater producing community.

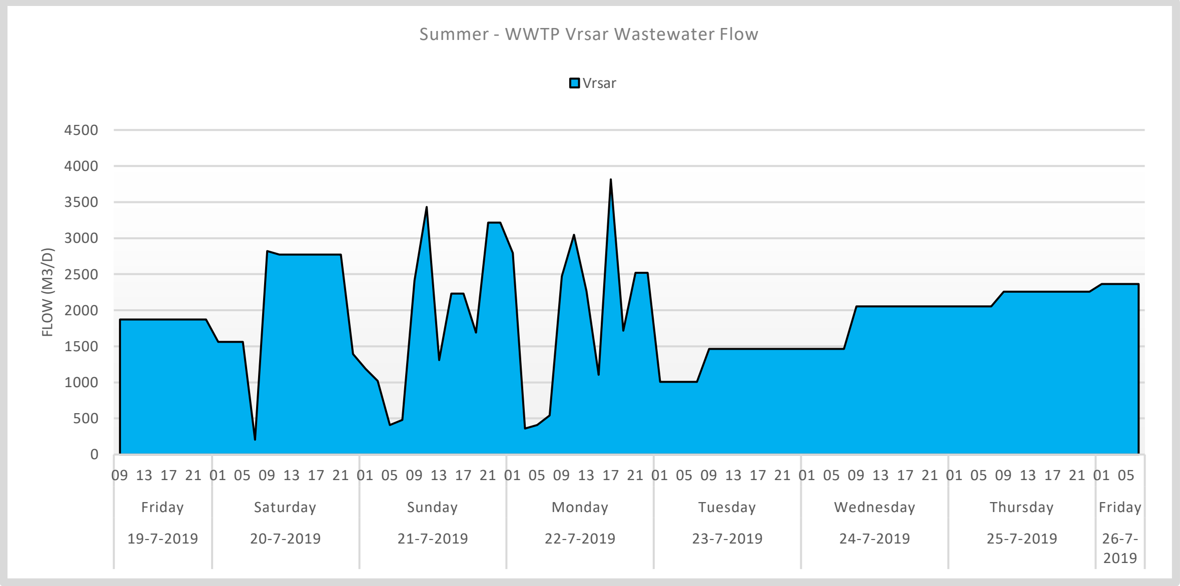


Figure 13. Summer - WWTP Vrsar Dry Weather Wastewater Flow 24-hour 7-day dynamic measurements. No rain events occurred during the measurements.

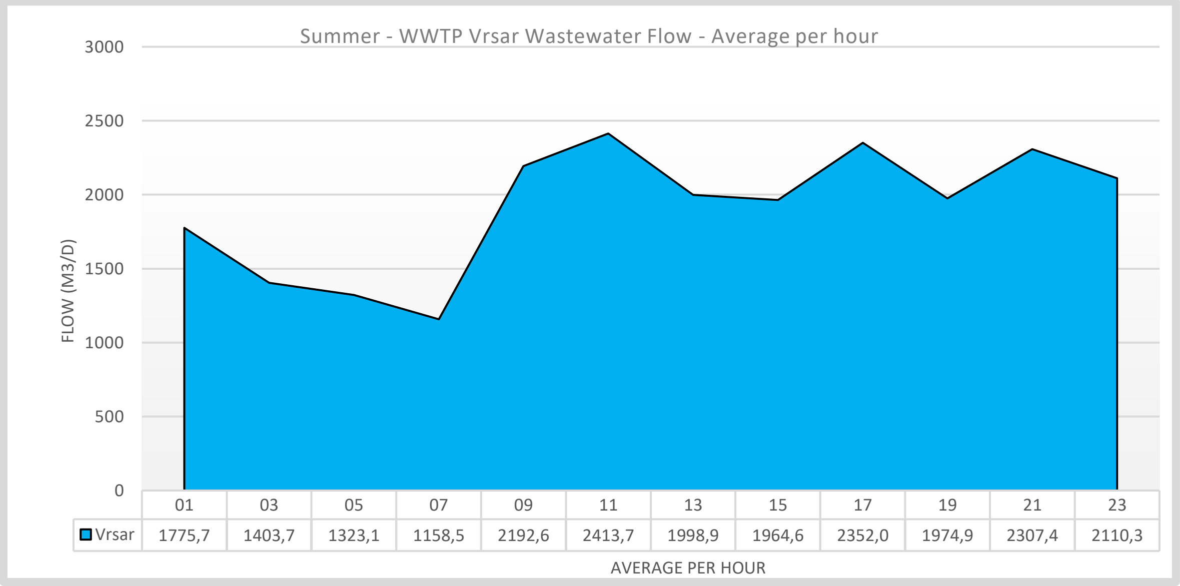


Figure 14. Summer - WWTP Vrsar Wastewater Flow 24-hour average hourly measurements. Data are used to reconstruct missing data in the flow measurements and for development of scenarios.

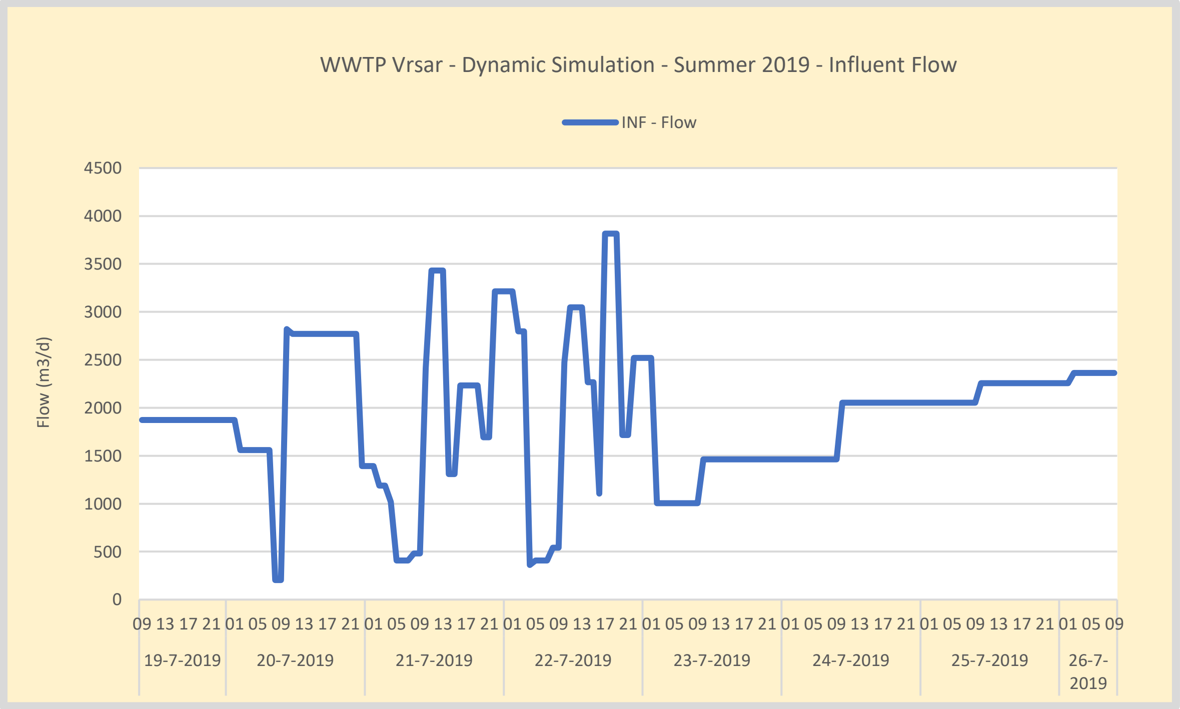


Figure 15. Summer – BioWin modelling WWTP Vrsar: Wastewater Flow 24-hour 7-day dynamic model input data. In the model data are interpolated on an hourly basis.

4.4 Conclusions flow measurements

From the flow measurements it is possible to reconstruct a continuous dynamic flow profile for modelling. Missing datapoints are reconstructed from the hourly average flow profile.

There is a significant difference in the amount of wastewater during the summer period (high season) and the rest of the year and winter period (low season).

During the winter, the total combined maximal produced wastewater flow is approximately 5.000 m3/d and the minimum 1.000 m3/d.

For Vrsar during winter this is between 530 and 140 m3/d.

During the summer, the total combined maximal produced wastewater flow is approximately 25.000 and minimum 5.000 m3/d.

For Vrsar during summer this is approximately 2.400 and 1.160 m3/d.

The wastewater flow is distributed over 24-hours according to a typical flow profile. These profiles are calculated based on an hourly average.

During the winter, the minimum flow occurs 5:00 and 7:00, the first flow peak comes around 13:00 and a second peak follows 1:00 in the morning. In the weekend generally fewer wastewater is produced.

During the summer, a different flow pattern is visible. The minimum flow is between 3:00 and 7:00 in the morning, the first peak comes around 11:00 and a second peak around 21:00. In the summer there is no drop of wastewater produced in the weekends. There seems to be a slightly higher peak Monday morning.

The flow in the sewar determines the sewage residence time and the time peaks of domestic source are measured at the treatment plant.

During summer, WWTP Vrsar shows a flow pattern that is less recognizable from the typical 24-hour flow pattern. Likely this is the result of the design and or capacity of the sewage system, sewage transport and operation of pumping stations. It sems that the flow pattern is determined by operation of transportation pumps. The winter flow pattern is typical recognizable four mainly domestic activity.

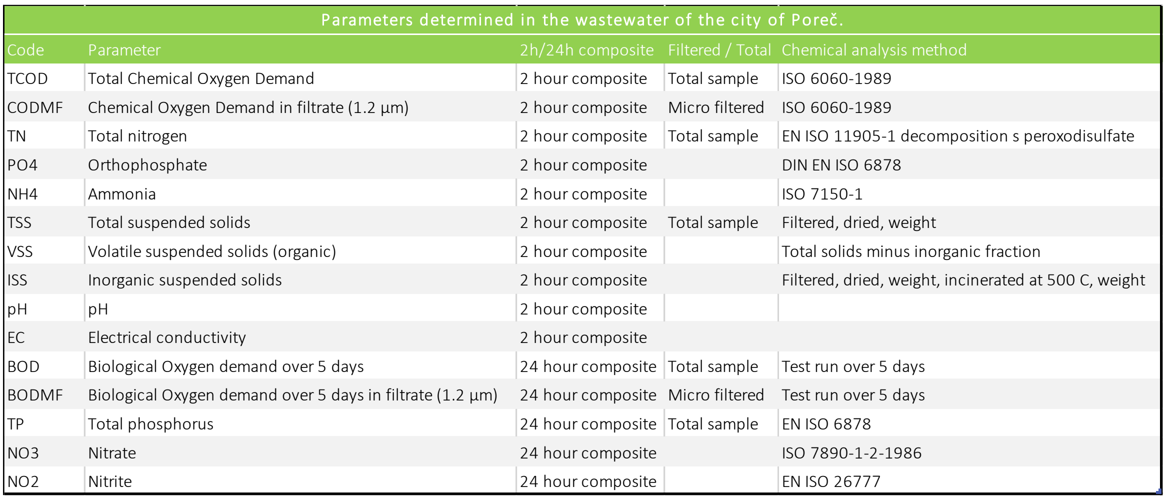
5 Influent quality sampling

5.1 Influent sampling and measurements

Raw sewage wastewater is sampled at all 4 WWTP locations. Continuous 24-hour automated samples are used for a continued period of seven days. Per wastewater location the sampling period is 7 days. This equals 168 hours resulting in 84 samples, each analyzed on 16 parameters including flow. The summer sampling commenced Friday July 19, 2019, at 9:00 AM and finished 7 days later Friday 26-07-2019 at 7:00. The winter sampling commenced Monday January 21, 2019, at 9:00 AM and finished 7 days later Monday 28-01-2019 7:00.

The type of sampler used is Hach AS950 Portable Sampler and WaterSam Ports. Samples are taken every 9-30 minutes (flow proportional) in bottles of volume 550–800 mL which are rotated automatically every 2 hours, for 24 h (total of 12 vessels collected per 24 hours for each sampling location). Every day during 7 days of operation the samplers are emptied, and the samples are taken to the laboratory for analysis (Zagreb Laboratory for Water Technology at the Faculty of Food Technology and Biotechnology). Three samplers are placed outdoors, and at the Poreč-North site a sampler was placed indoors. Samplers placed outdoors were thermally insulated and refrigerated.

Table 4. Parameters measured in wastewater.



Parameters determined in the wastewater of the city of Poreč.				
Code	Parameter	2h/24h composite	Filtered / Total	Chemical analysis method
TCOD	Total Chemical Oxygen Demand	2 hour composite	Total sample	ISO 6060-1989
CODMF	Chemical Oxygen Demand in filtrate (1.2 µm)	2 hour composite	Micro filtered	ISO 6060-1989
TN	Total nitrogen	2 hour composite	Total sample	EN ISO 11905-1 decomposition s peroxodisulfate
PO4	Orthophosphate	2 hour composite		DIN EN ISO 6878
NH4	Ammonia	2 hour composite		ISO 7150-1
TSS	Total suspended solids	2 hour composite	Total sample	Filtered, dried, weight
VSS	Volatile suspended solids (organic)	2 hour composite		Total solids minus inorganic fraction
ISS	Inorganic suspended solids	2 hour composite		Filtered, dried, weight, incinerated at 500 C, weight
pH	pH	2 hour composite		
EC	Electrical conductivity	2 hour composite		
BOD	Biological Oxygen demand over 5 days	24 hour composite	Total sample	Test run over 5 days
BODMF	Biological Oxygen demand over 5 days in filtrate (1.2 µm)	24 hour composite	Micro filtered	Test run over 5 days
TP	Total phosphorus	24 hour composite	Total sample	EN ISO 6878
NO3	Nitrate	24 hour composite		ISO 7890-1-2-1986
NO2	Nitrite	24 hour composite		EN ISO 26777

5.2 Time average versus flow-proportional concentration

In this study model calculations are based on 24-hour dynamic influent flow and concentration dynamics and static daily average flow and concentrations. Two different methods are used to determine these flows and concentrations.

The hourly concentration is measured using an automatic flow-proportional sampler, with a sampling rotor containing 12 sampling vessels. An empty vessel is rotated in to place every 2-hours over a 24-hour period. Sample volumes are collected using a flow proportional sampling method. Therefore, the sampling pump is controlled based on measurement of the influent flow. The influent flow measurement gives a pulse to a sampling pump every time a certain influent volume is measured. The sampling frequency thereby increases proportionally with the measured influent flow. The sample volume is determined by a preset running time of the sampling pump each time it is activated by the flow meter. The combination of sampling pump operation frequency and running time is set-up in a way the maximum collected volume over a 2-hour period never exceeds the volume of the sample vessel. Thereby the sampler also should take a minimum amount of sample every 2-hours to satisfy the volume requirements for the laboratory, even when the influent flow is at its minimum.

With a daily flow variation, this 24-hour sampling method results in a sample rotor with each of the 12 vessels filled at variable volume, dependent on influent flow which was measured during the 2-hour sample interval. The content of each vessel is a mixed composition of influent samples (pulses) in which high flow conditions are more frequently sampled. Laboratory analysis of each mixed 2-hour sample represents the average flow proportional concentration for that 2-hour period. Based on 12 samples a 24-hour dynamic concentration profile is obtained which can be used for modelling purposes.

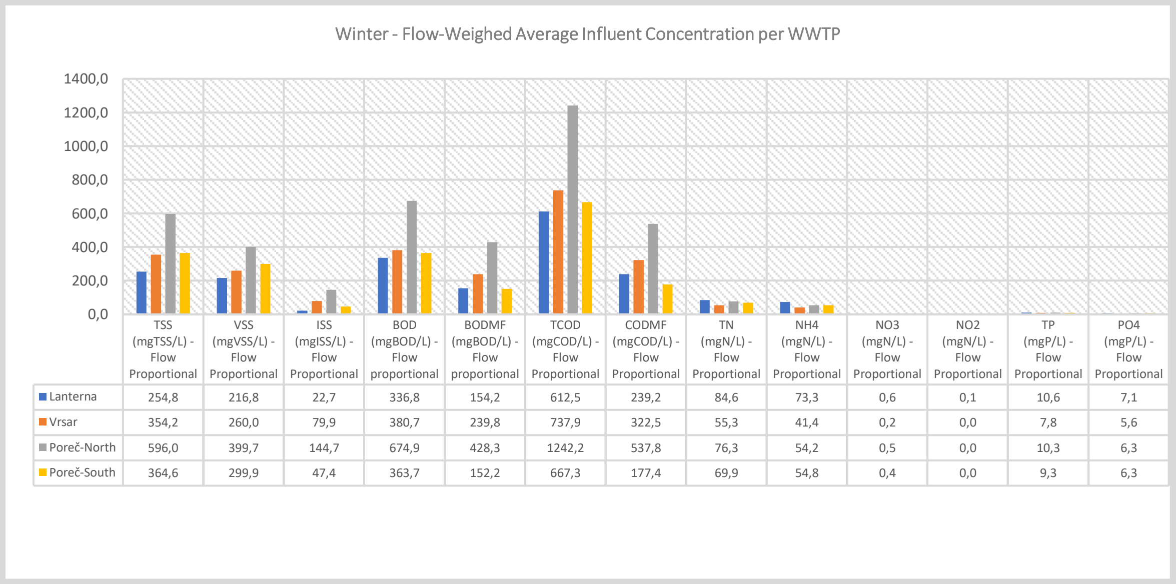
For static modeling, the 2-hour interval concentration measurements are used to calculate a daily average flow proportional concentration. This is done for each measured influent parameter. By multiplying the 2-hour composite concentration with the measured influent volume over the same 2-hour period, the 2-hour interval influent load is obtained. The daily influent load over 24-hours is obtained by taking the sum of the 12 calculated 2-hour loads. The daily average flow weighed concentration is obtained by dividing the daily load by the daily influent flow. Only flow weighed concentration data are used for static design and model calculations.

An incorrect method of applying concentration measurements in modeling, is calculating the average concentration directly from concentration measurements without weighing. Thus, not taking in consideration the flow conditions under which concentrations are measured. When using these data for design calculations, the plant loading will be underestimated when more rain events are measured and overestimated when more dry weather events are measured. At a rain event, the concentration is low as result of dilution of influent however, the plant loading is increased due to the increased flow. During dry weather relative concentrated influent may be measured, however the loading effect on the plant is limited due to often lower flow conditions. The following graph shows the flow-weighed influent concentrations for each of the treatment plants in the Poreč area.

5.3 Average influent concentration

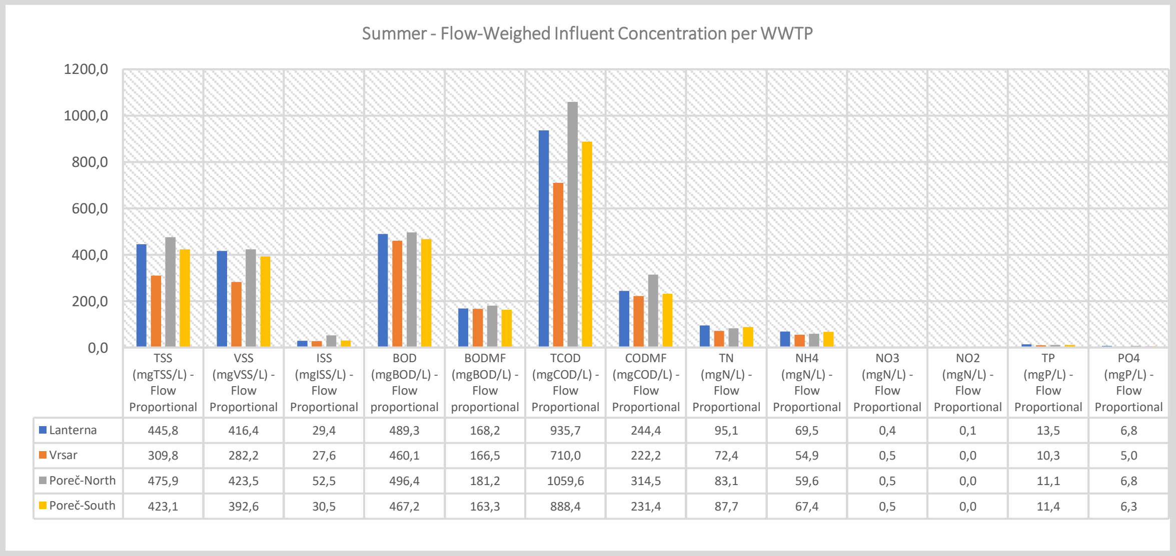
For each 2-hour composite sample the concentration was measured of all parameters. Also, the total flow for that period was measured. These data are used to calculate the influent loads every 2-hours. From these data the daily average load flow and flow proportional (weighed) concentration is calculated. Only the weighed concentration is used in the design calculations. The average data was already presented in the report Step 1 but in this report the total influent data analysis is made.

The results of the summer and winter measurements are presented in the graphs below. During the summer, the concentrations of wastewater are slightly higher, most likely due to absence of rain and less water infiltration. TSS and VSS and other particulate fractions seem to increase relative to the other fractions. This could be caused by the shorter sewer residence time due to an increased flow and better mixing. Hydrolysis of particulate matter could be less in the summer due to a decreased time in the sewer system.



	TSS (mgTSS/L) - Flow Proportional	VSS (mgVSS/L) - Flow Proportional	ISS (mgISS/L) - Flow Proportional	BOD (mgBOD/L) - Flow proportional	BODMF (mgBOD/L) - Flow proportional	TCOD (mgCOD/L) - Flow Proportional	CODMF (mgCOD/L) - Flow Proportional	TN (mgN/L) - Flow Proportional	NH4 (mgN/L) - Flow Proportional	NO3 (mgN/L) - Flow Proportional	NO2 (mgN/L) - Flow Proportional	TP (mgP/L) - Flow Proportional	PO4 (mgP/L) - Flow Proportional
■ Lanterna	254,8	216,8	22,7	336,8	154,2	612,5	239,2	84,6	73,3	0,6	0,1	10,6	7,1
■ Vrsar	354,2	260,0	79,9	380,7	239,8	737,9	322,5	55,3	41,4	0,2	0,0	7,8	5,6
■ Poreč-North	596,0	399,7	144,7	674,9	428,3	1242,2	537,8	76,3	54,2	0,5	0,0	10,3	6,3
■ Poreč-South	364,6	299,9	47,4	363,7	152,2	667,3	177,4	69,9	54,8	0,4	0,0	9,3	6,3

Figure 16. Winter - Flow-Weighed Average Influent Concentration per WWTP. Wastewater concentrations are more diluted relative to summer.



	TSS (mgTSS/L) - Flow Proportional	VSS (mgVSS/L) - Flow Proportional	ISS (mgISS/L) - Flow Proportional	BOD (mgBOD/L) - Flow proportional	BODMF (mgBOD/L) - Flow proportional	TCOD (mgCOD/L) - Flow Proportional	CODMF (mgCOD/L) - Flow Proportional	TN (mgN/L) - Flow Proportional	NH4 (mgN/L) - Flow Proportional	NO3 (mgN/L) - Flow Proportional	NO2 (mgN/L) - Flow Proportional	TP (mgP/L) - Flow Proportional	PO4 (mgP/L) - Flow Proportional
■ Lanterna	445,8	416,4	29,4	489,3	168,2	935,7	244,4	95,1	69,5	0,4	0,1	13,5	6,8
■ Vrsar	309,8	282,2	27,6	460,1	166,5	710,0	222,2	72,4	54,9	0,5	0,0	10,3	5,0
■ Poreč-North	475,9	423,5	52,5	496,4	181,2	1059,6	314,5	83,1	59,6	0,5	0,0	11,1	6,8
■ Poreč-South	423,1	392,6	30,5	467,2	163,3	888,4	231,4	87,7	67,4	0,5	0,0	11,4	6,3

Figure 17. Summer - Flow-Weighed Average Influent Concentration per WWTP.

5.4 Dynamic 24-hour influent concentration profiles

Due to a range of variables and possible measurement errors, the concentration of wastewater varies over time. However, there is a distinct 24-hour hourly profile caused by mainly human regular activity over the day and week. These profiles are calculated for each measured parameter and presented in the figures below.

What time the wastewater concentration peaks over the day, mainly is caused by the sewage flow. High flow results in short sewer residence time and peaks early in the day, while low flow results in concentration peaks later in the day. Especially transport of particulate material is dependent on the flow velocity in the sewer system. During the winter, it takes considerably longer before particulate material arrives at the WWTP. This material settles overnight in the sewer and is collected in the morning when the flow increases.

Ammonia and orthophosphate are typically produced by human activity in the form of urine in the morning. The time these peaks are measured at the WWTP is an indicator for the average residence time in the sewar system. This effect is clearly observed from the data by comparing the first peak during summer and winter conditions in the figures below.

The hourly average 24-hour profiles are used to reconstruct the influent data for modelling and fill in missing samples. The 24-hour hourly average profiles can also be used to develop wastewater scenarios. This is done in Step 3 of this research.

5.5 COD Influent concentration - winter and summer

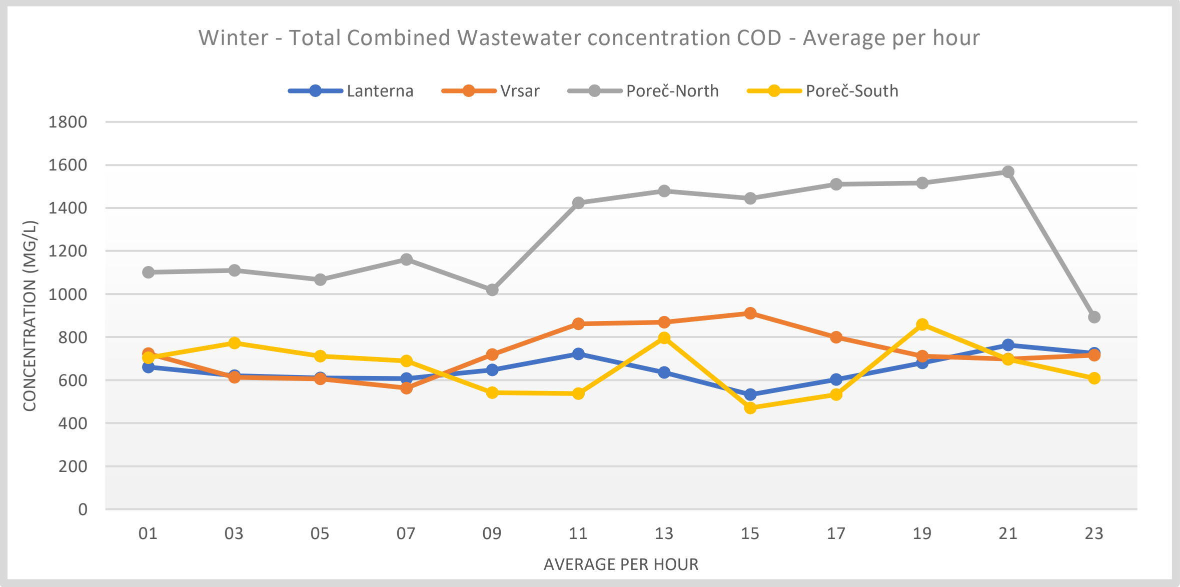
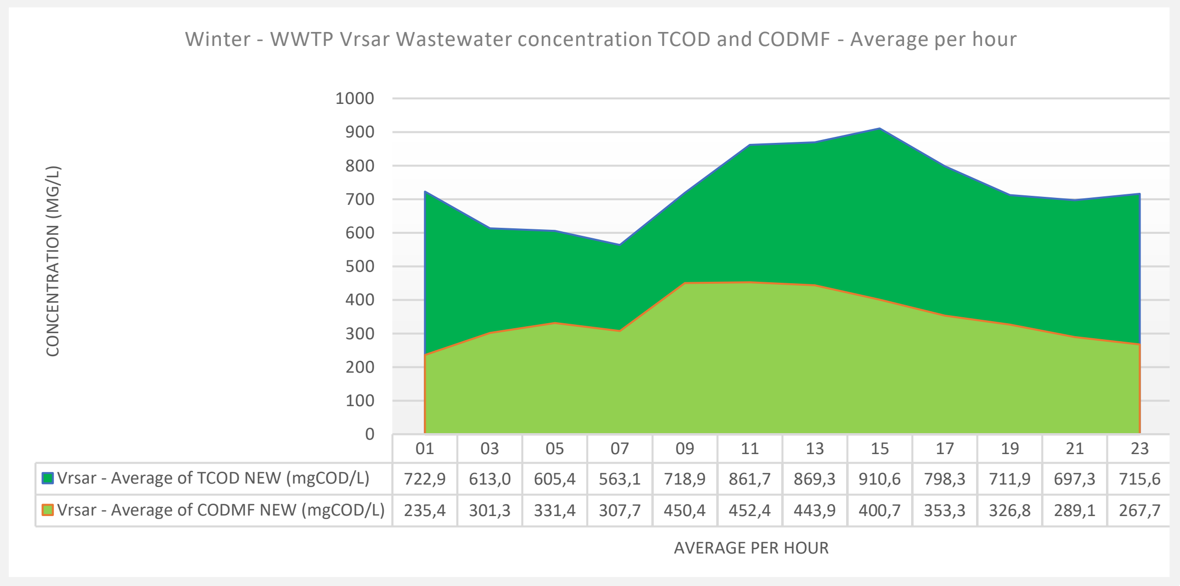


Figure 18. Winter – 24-hour average COD Influent Concentration per WWTP.



	01	03	05	07	09	11	13	15	17	19	21	23
🟩 Vrsar - Average of TCOD NEW (mgCOD/L)	722,9	613,0	605,4	563,1	718,9	861,7	869,3	910,6	798,3	711,9	697,3	715,6
🟩 Vrsar - Average of CODMF NEW (mgCOD/L)	235,4	301,3	331,4	307,7	450,4	452,4	443,9	400,7	353,3	326,8	289,1	267,7

Figure 19. Winter – WWTP Vrsar 24-hour average COD and COD micro-filtered influent Concentration.

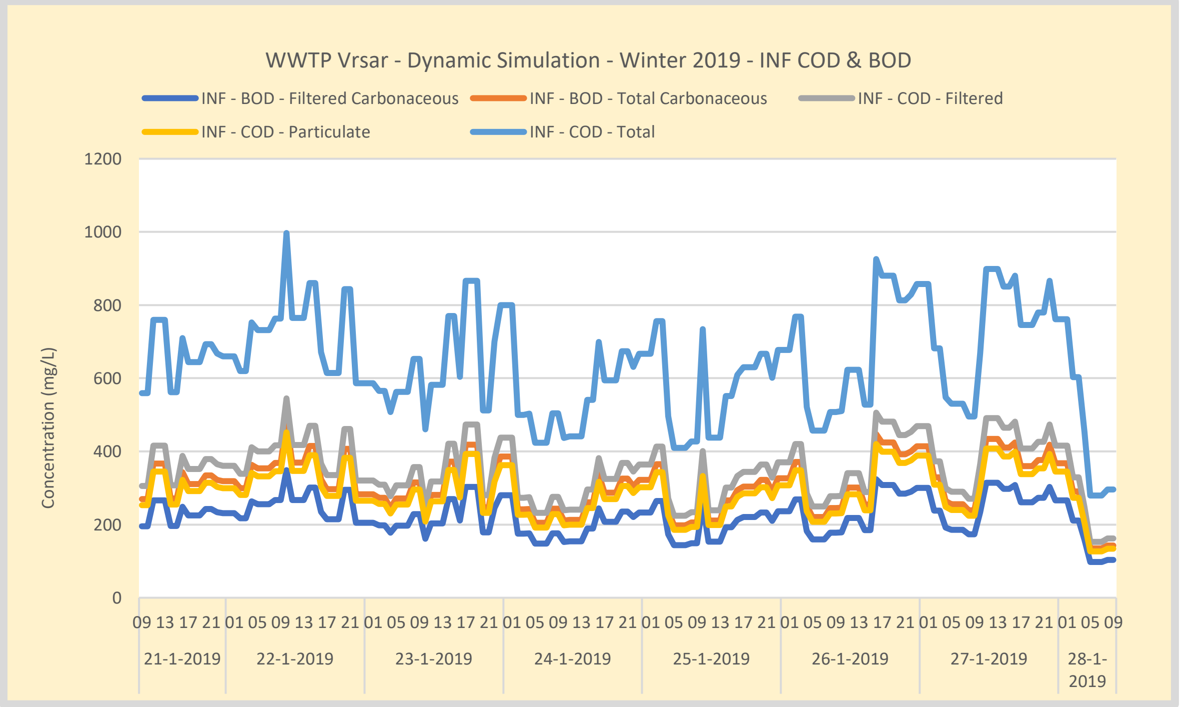


Figure 20. Dynamic Simulation – WWTP Vrsar – Winter 24-hour average COD, COD micro-filtered, COD particulate, BOD and BOD filtered influent Concentration. The model input is the measured and reconstructed COD concentration. The other lines are calculated based on (constant) fractions determined in the influent specification. 28-01-2019 a major rain event occurred causing a sharp drop in the influent COD concentration. There is no indication of discharges.

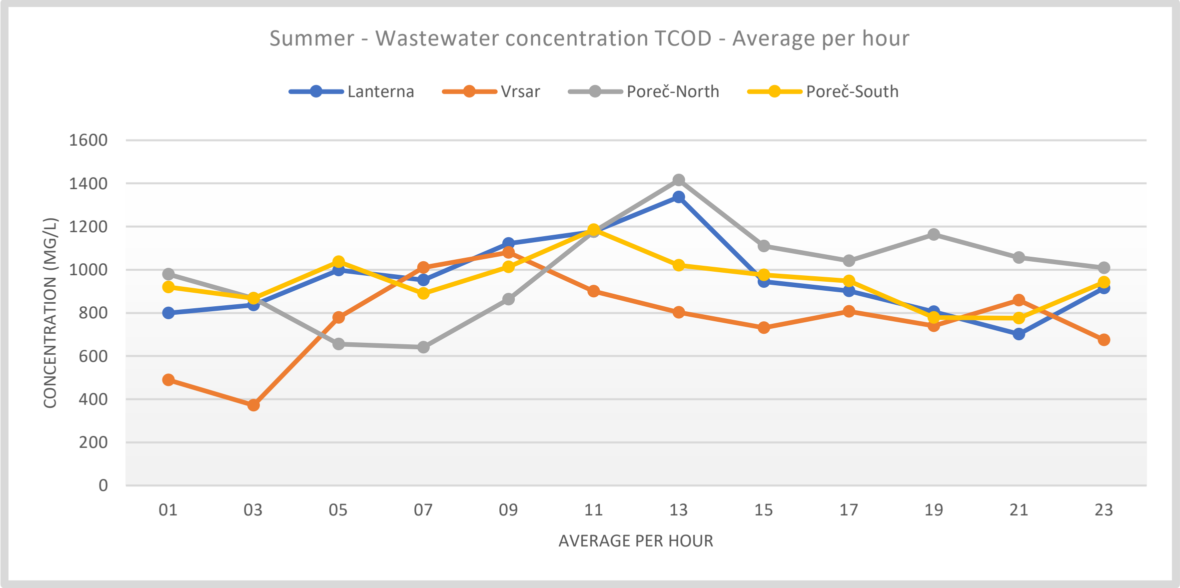
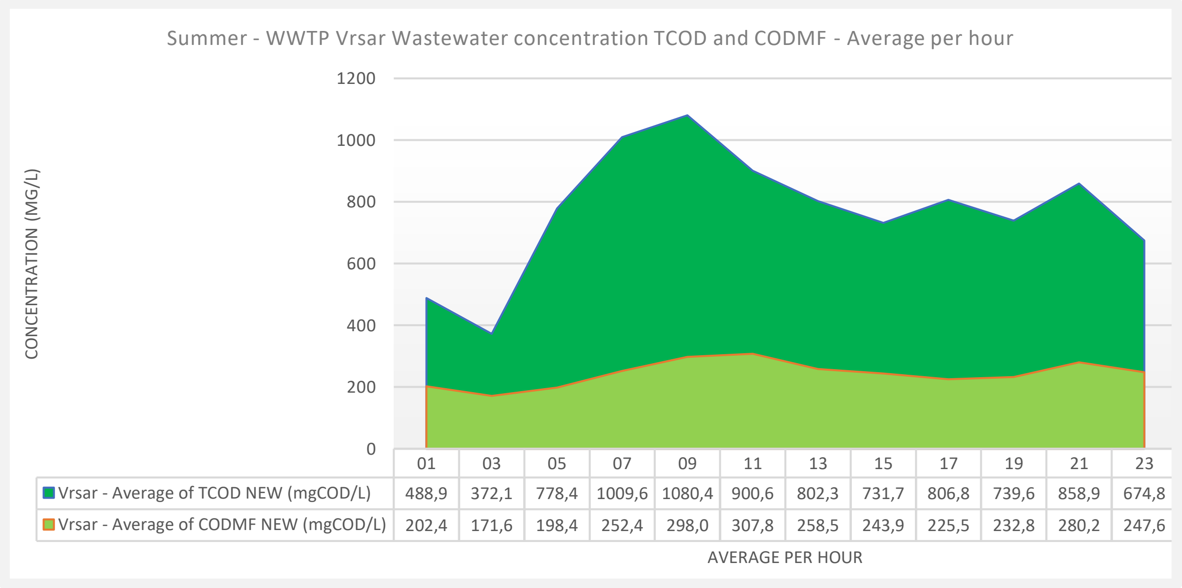


Figure 21. Summer – 24-hour average COD Influent Concentration per WWTP.



	01	03	05	07	09	11	13	15	17	19	21	23
🟩 Vrsar - Average of TCOD NEW (mgCOD/L)	488,9	372,1	778,4	1009,6	1080,4	900,6	802,3	731,7	806,8	739,6	858,9	674,8
🟩 Vrsar - Average of CODMF NEW (mgCOD/L)	202,4	171,6	198,4	252,4	298,0	307,8	258,5	243,9	225,5	232,8	280,2	247,6

Figure 22. Summer – WWTP Vrsar 24-hour average COD and COD micro-filtered influent Concentration. While soluble COD is relative constant the total which also contains the particulate is more distributed towards the first flow peak of the day.

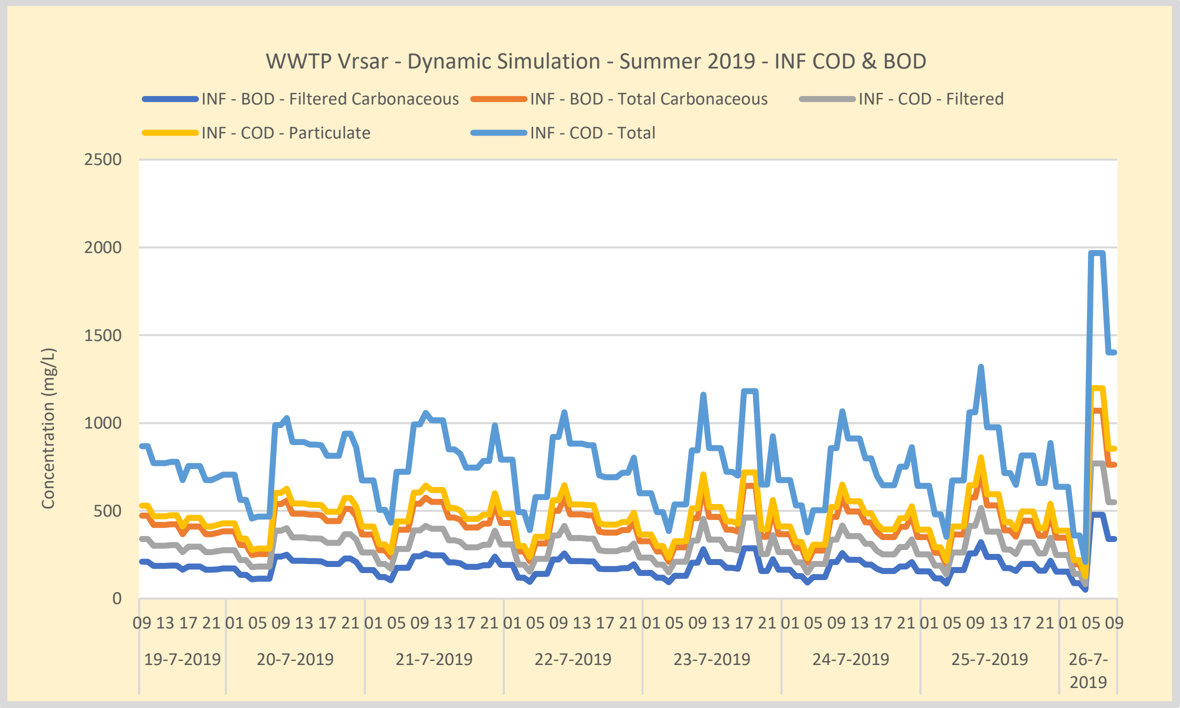


Figure 23. Dynamic Simulation – WWTP Vrsar – Summer 24-hour average COD, COD micro-filtered, COD particulate, BOD and BOD filtered influent Concentration. The model input is the measured and reconstructed COD concentration. The other lines are calculated based on (constant) fractions determined in the influent specification. 26-7-2019 a COD concentration peak was measured. A peak is measured 26-7 indicating nondomestic discharge.

5.6 Nitrogen influent concentration – winter and summer

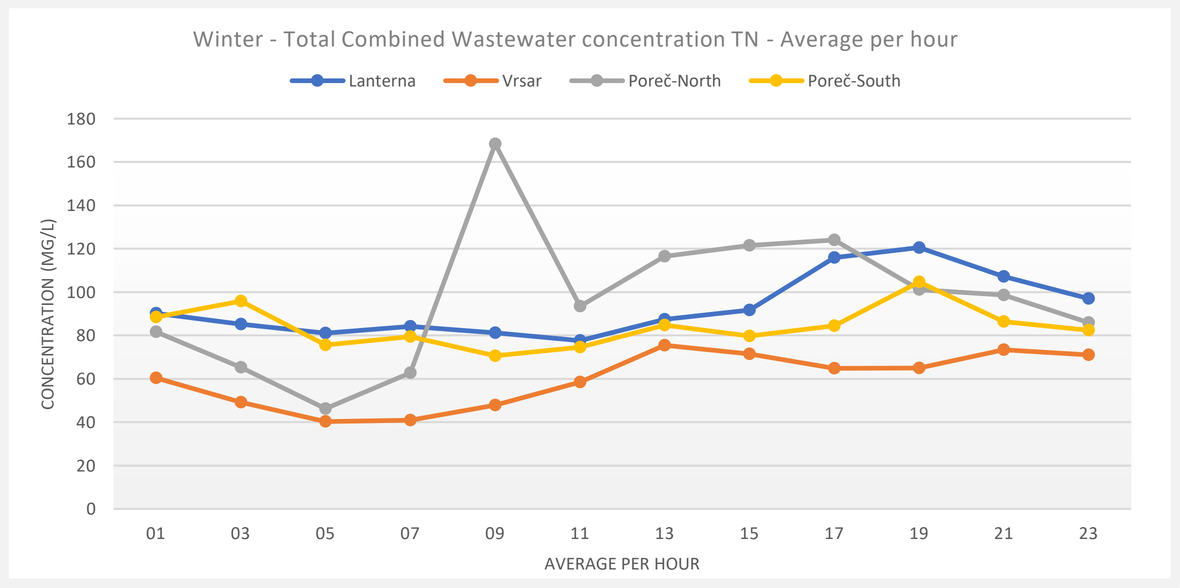
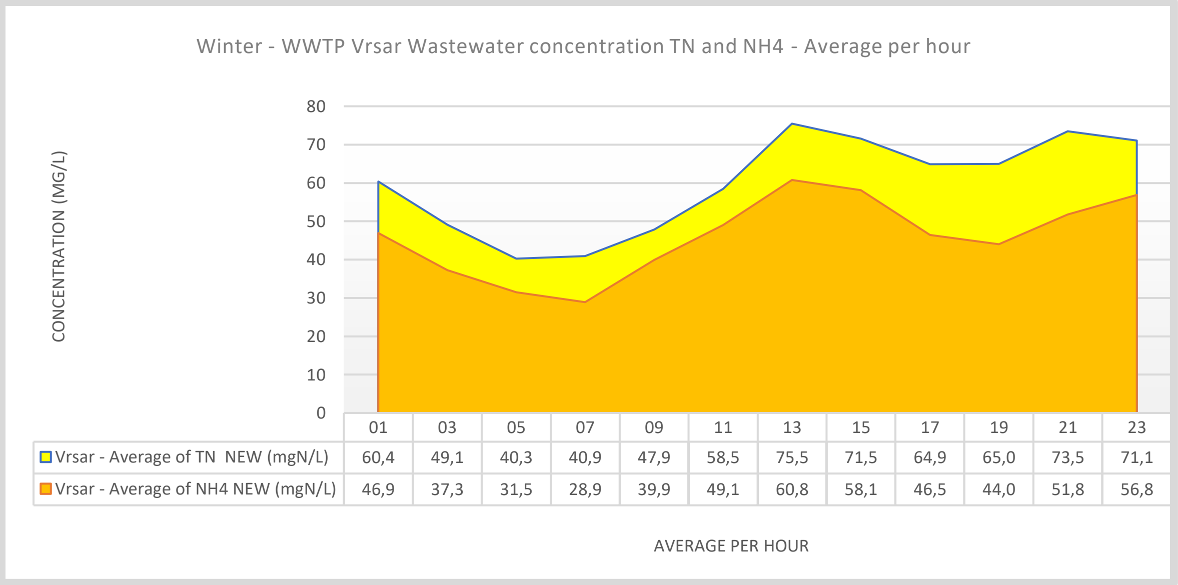


Figure 24. Winter – 24-hour average TN Influent Concentration per WWTP.



	01	03	05	07	09	11	13	15	17	19	21	23
🟨 Vrsar - Average of TN NEW (mgN/L)	60,4	49,1	40,3	40,9	47,9	58,5	75,5	71,5	64,9	65,0	73,5	71,1
🟧 Vrsar - Average of NH4 NEW (mgN/L)	46,9	37,3	31,5	28,9	39,9	49,1	60,8	58,1	46,5	44,0	51,8	56,8

Figure 25. Winter – WWTP Vrsar 24-hour average TN and NH4 influent Concentration.

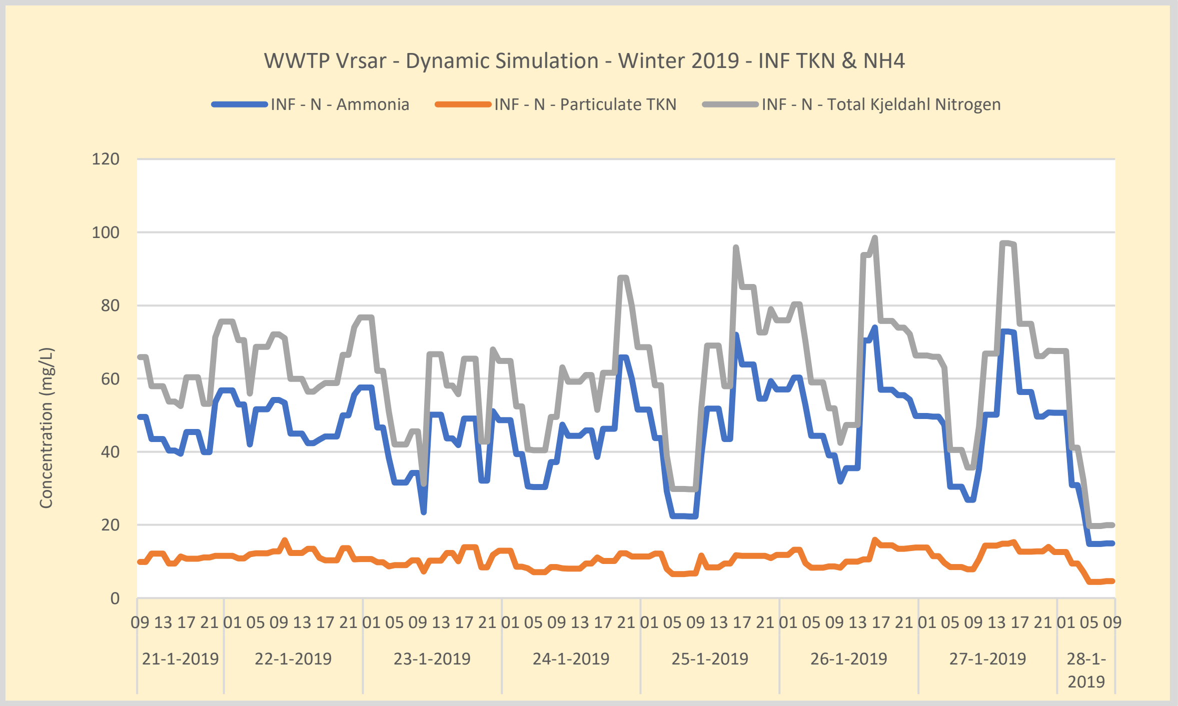


Figure 26. Dynamic Simulation – WWTP Vrsar – Winter 24-hour average TKN, NH4 and particulate TKN influent Concentration. The model input is the measured and reconstructed TKN concentration. The other lines are calculated based on (constant) fractions determined in the influent specification. 28-01-2019 a major rain event occurred causing a sharp drop in the influent concentration. No exceptional peaks occurred.

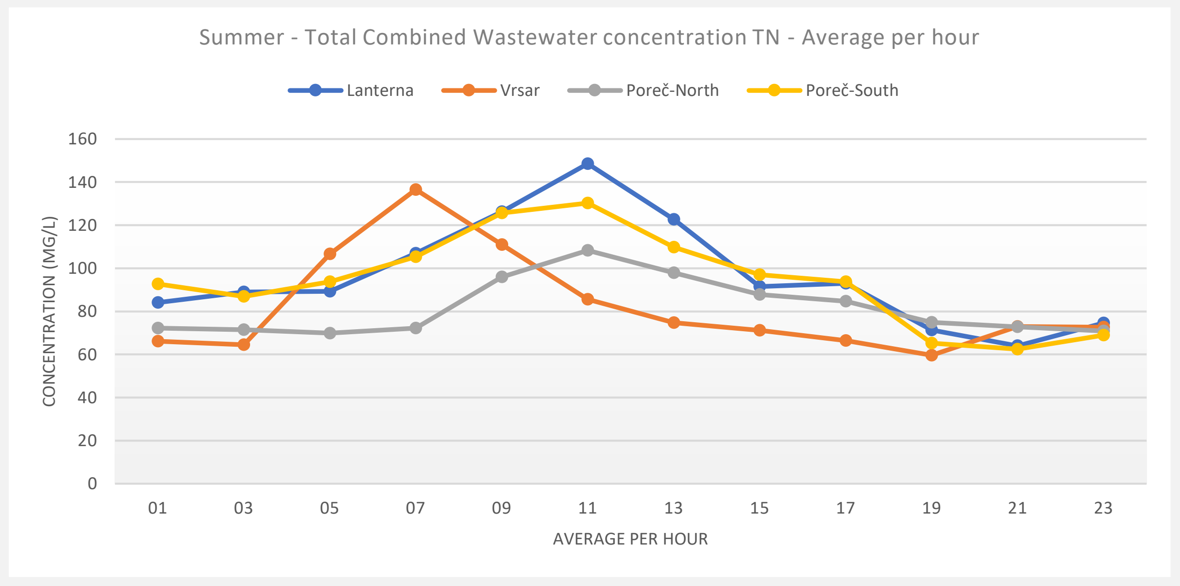
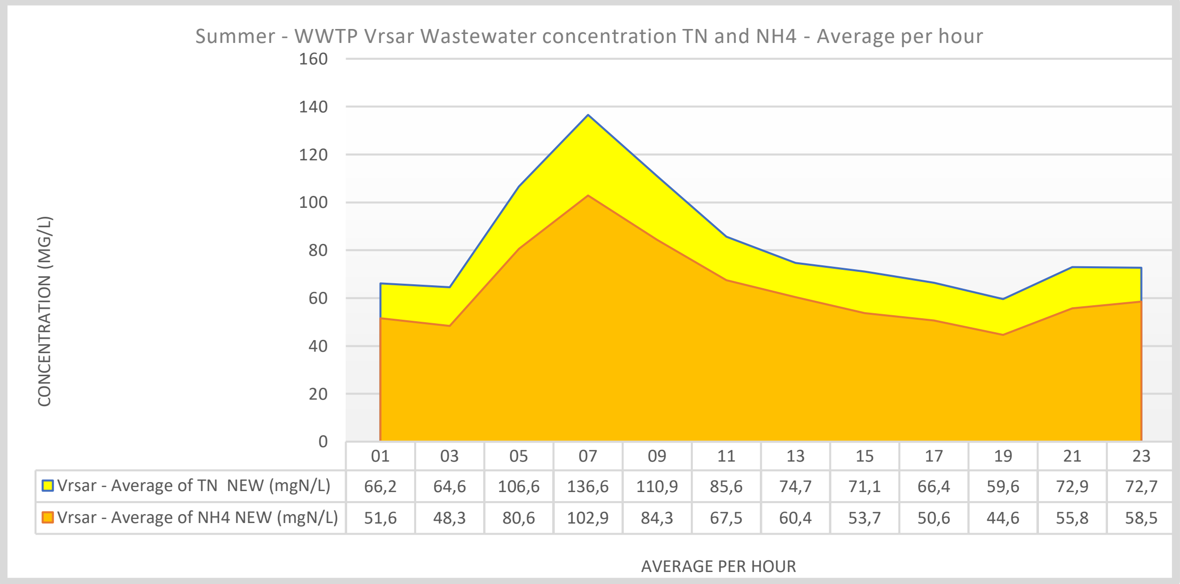


Figure 27. Summer – 24-hour average TN Influent Concentration per WWTP.



	01	03	05	07	09	11	13	15	17	19	21	23
🟨 Vrsar - Average of TN NEW (mgN/L)	66,2	64,6	106,6	136,6	110,9	85,6	74,7	71,1	66,4	59,6	72,9	72,7
🟧 Vrsar - Average of NH4 NEW (mgN/L)	51,6	48,3	80,6	102,9	84,3	67,5	60,4	53,7	50,6	44,6	55,8	58,5

Figure 28. Summer – WWTP Vrsar 24-hour average TN and NH4 influent Concentration. A typical distribution with peak in the morning. Vrsar shows to have a short sewar residence time during the summer.

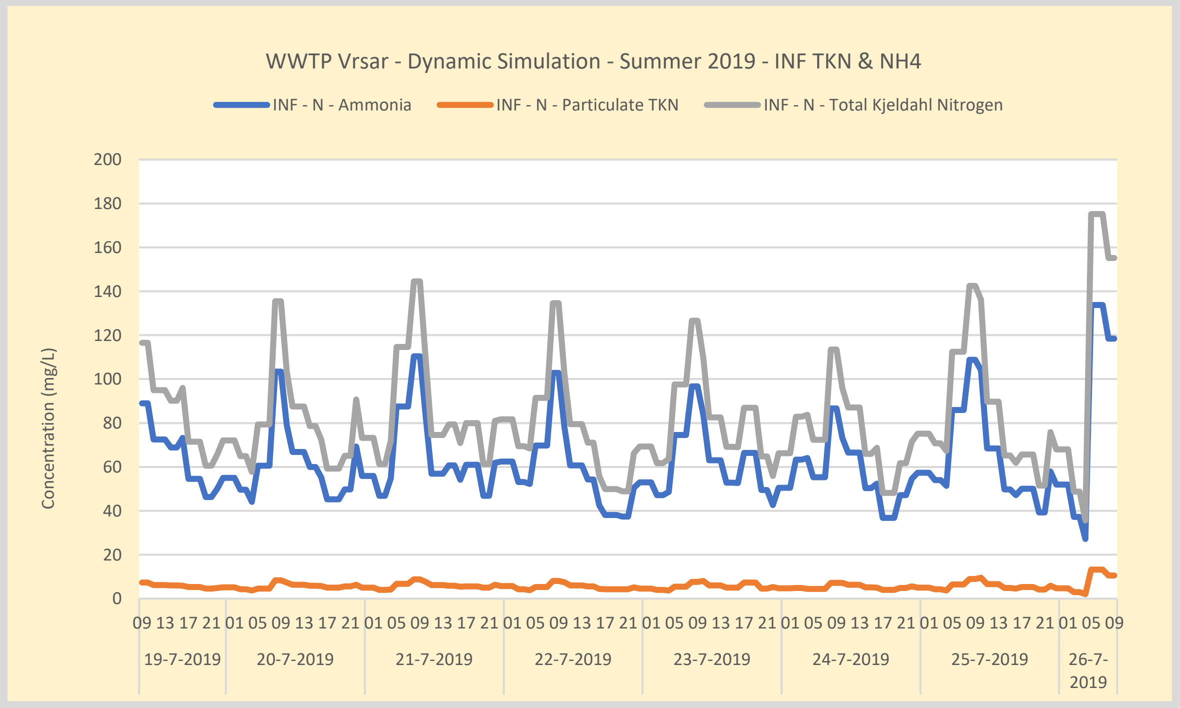


Figure 29. Dynamic Simulation – WWTP Vrsar – Summer 24-hour average TKN, NH4 and particulate TKN influent Concentration. The model input is the measured and reconstructed TKN concentration. The other lines are calculated based on (constant) fractions determined in the influent specification. 26-7-2019 a TN concentration peak was measured coinciding with COD.

5.7 Phosphorus influent concentration – winter and summer

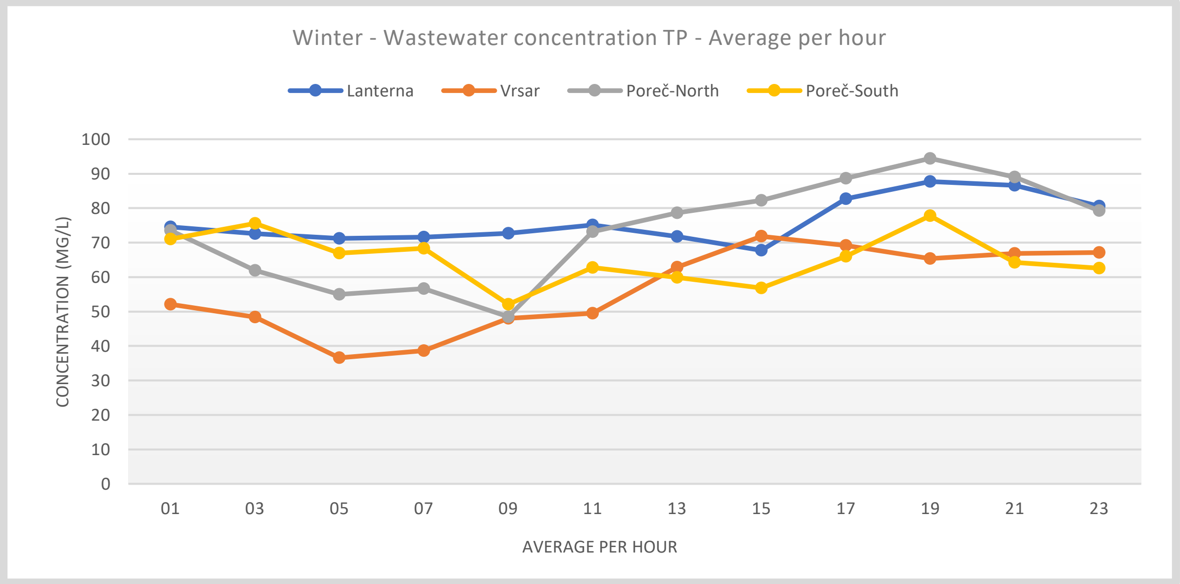


Figure 30. Winter – 24-hour average TP Influent Concentration per WWTP.

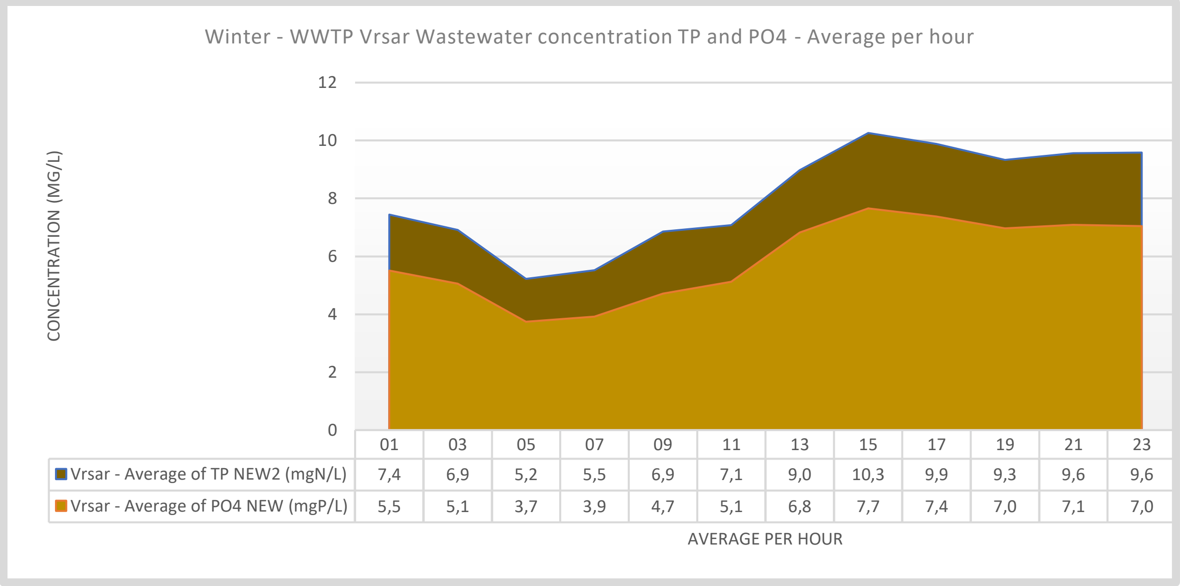


Figure 31. Winter – WWTP Vrsar 24-hour average TP and PO4 influent Concentration.

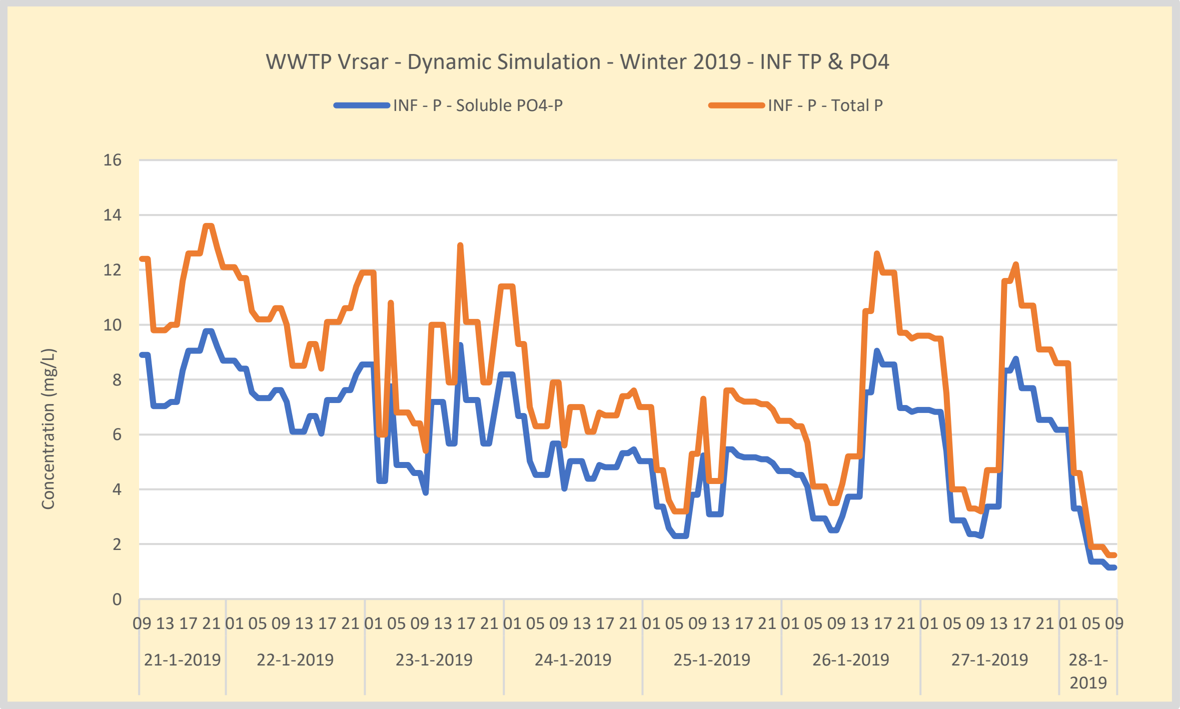


Figure 32. Dynamic Simulation – WWTP Vrsar – Winter 24-hour average TP and PO4 influent Concentration. The model input is the measured and reconstructed TP concentration. PO4 is calculated based on a (constant) fraction determined in the influent specification. 28-01-2019 a major rain event occurred causing a sharp drop in the influent concentration. The concentration profile at the start of the week is not typical which may indicate problems with the analytical measurements.

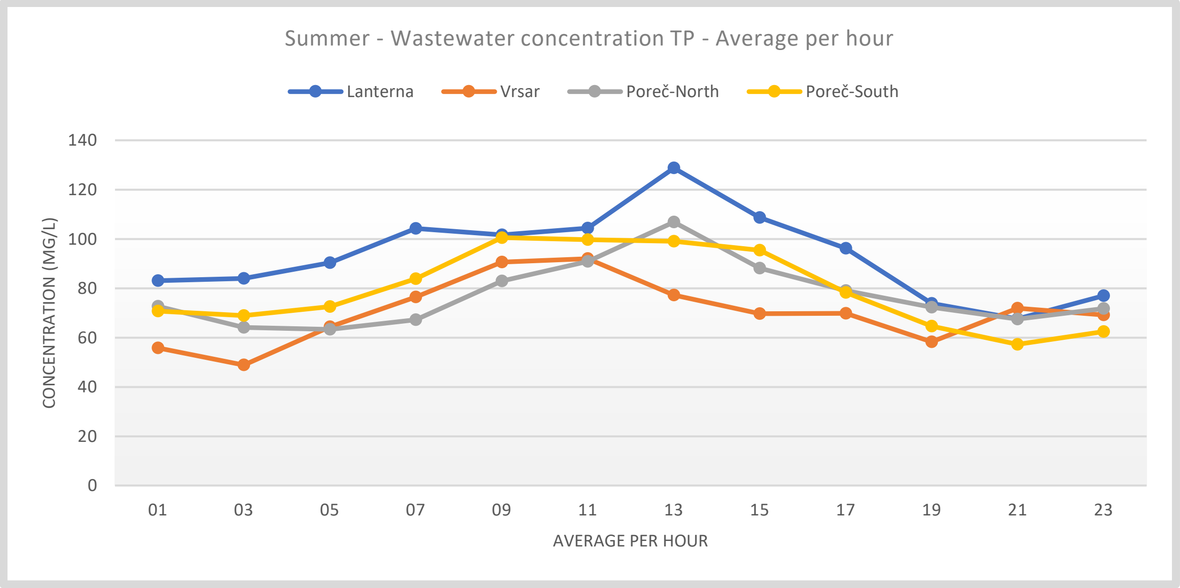
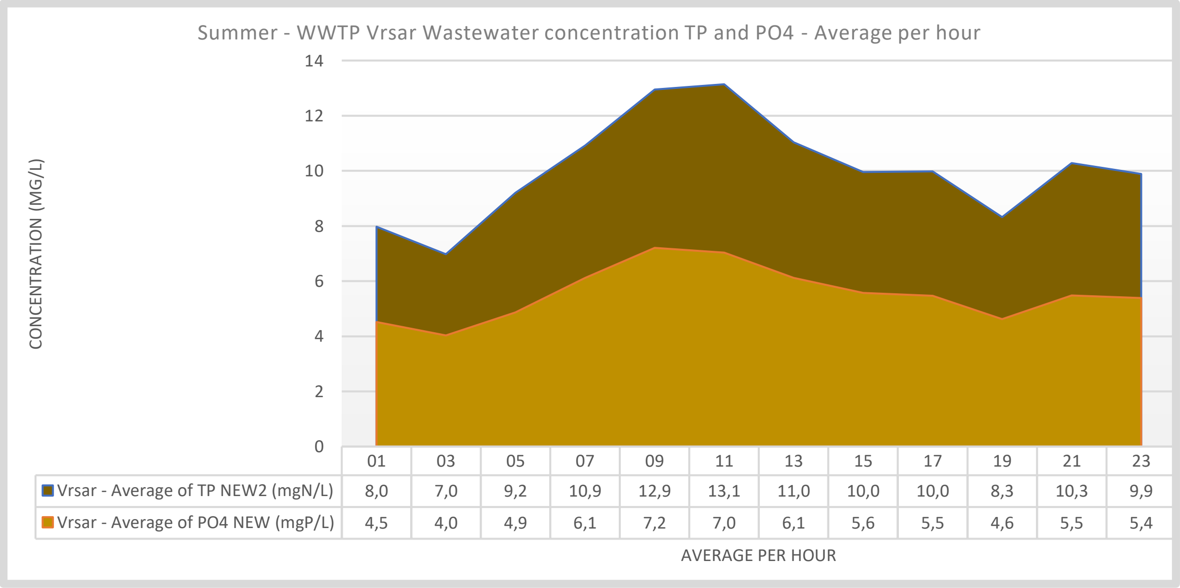


Figure 33. Summer – 24-hour average TP Influent Concentration per WWTP.



	01	03	05	07	09	11	13	15	17	19	21	23
■ Vrsar - Average of TP NEW2 (mgN/L)	8,0	7,0	9,2	10,9	12,9	13,1	11,0	10,0	10,0	8,3	10,3	9,9
■ Vrsar - Average of PO4 NEW (mgP/L)	4,5	4,0	4,9	6,1	7,2	7,0	6,1	5,6	5,5	4,6	5,5	5,4

Figure 34. Summer – WWTP Vrsar 24-hour average TP and PO4 influent Concentration. The figure shows a typical concentration distribution for domestic sewage, in accordance with TN, with a peak in the morning. TP has a larger particulate fraction which results in a peak arriving later in the day compared to TN.

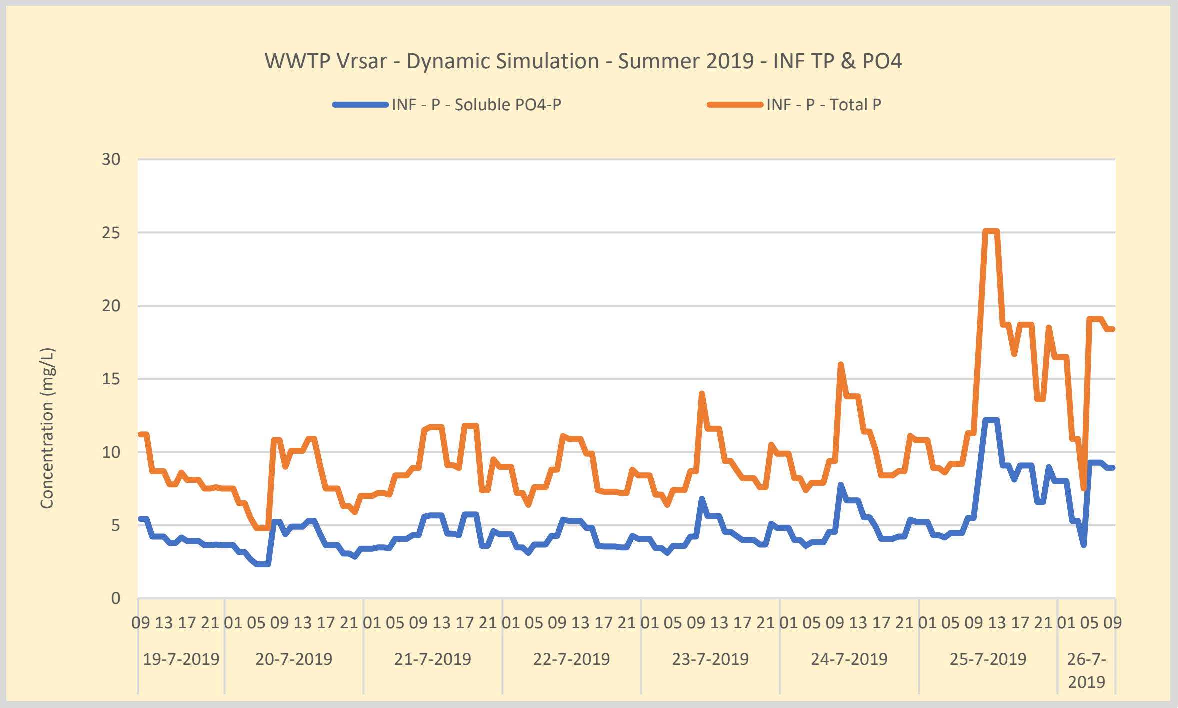


Figure 35. Dynamic Simulation – WWTP Vrsar – Summer 24-hour average TP and PO4 Concentration. The model input is the measured and reconstructed TP concentration. PO4 is calculated based on a (constant) fraction determined in the influent specification. A concentration peak and possible high P-discharge is measured 25-07-2019.

5.8 Total Suspended Solids influent concentration – winter and summer

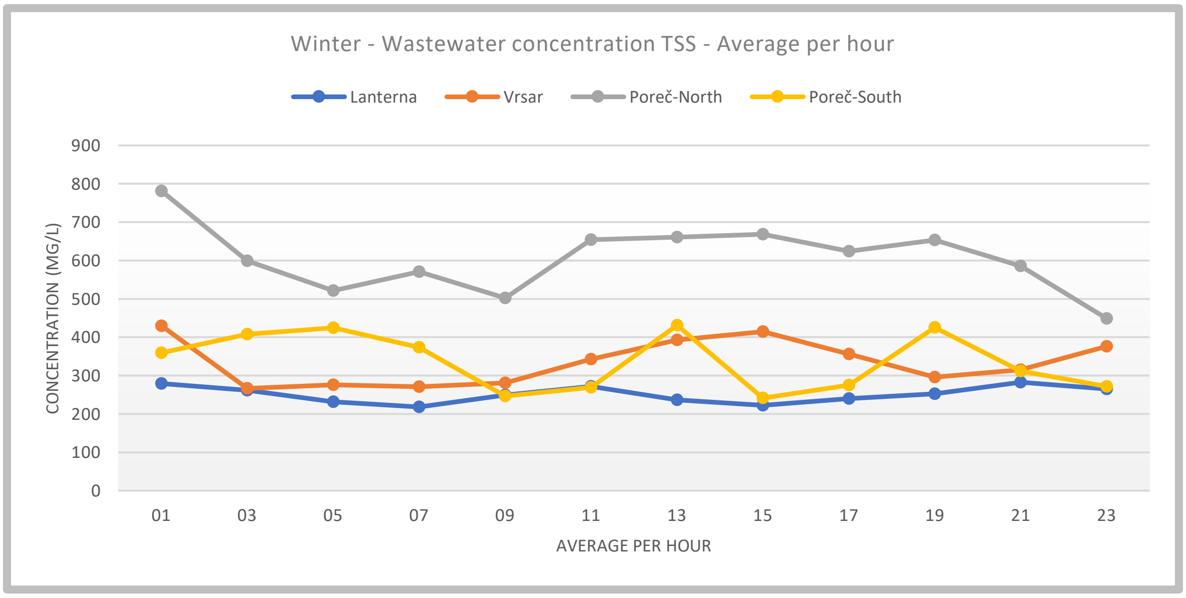
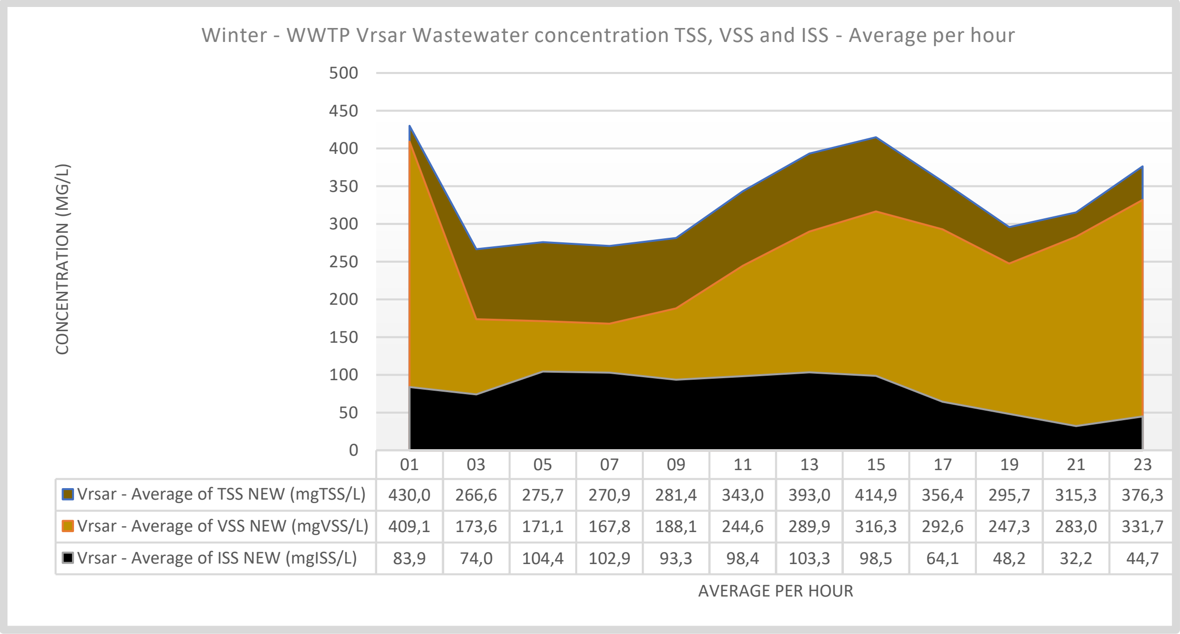


Figure 36. Winter – 24-hour average TSS Influent Concentration per WWTP.



	01	03	05	07	09	11	13	15	17	19	21	23
Vrsar - Average of TSS NEW (mgTSS/L)	430,0	266,6	275,7	270,9	281,4	343,0	393,0	414,9	356,4	295,7	315,3	376,3
Vrsar - Average of VSS NEW (mgVSS/L)	409,1	173,6	171,1	167,8	188,1	244,6	289,9	316,3	292,6	247,3	283,0	331,7
Vrsar - Average of ISS NEW (mgISS/L)	83,9	74,0	104,4	102,9	93,3	98,4	103,3	98,5	64,1	48,2	32,2	44,7

Figure 37. Winter – WWTP Vrsar 24-hour average TSS, VSS and ISS influent Concentration.

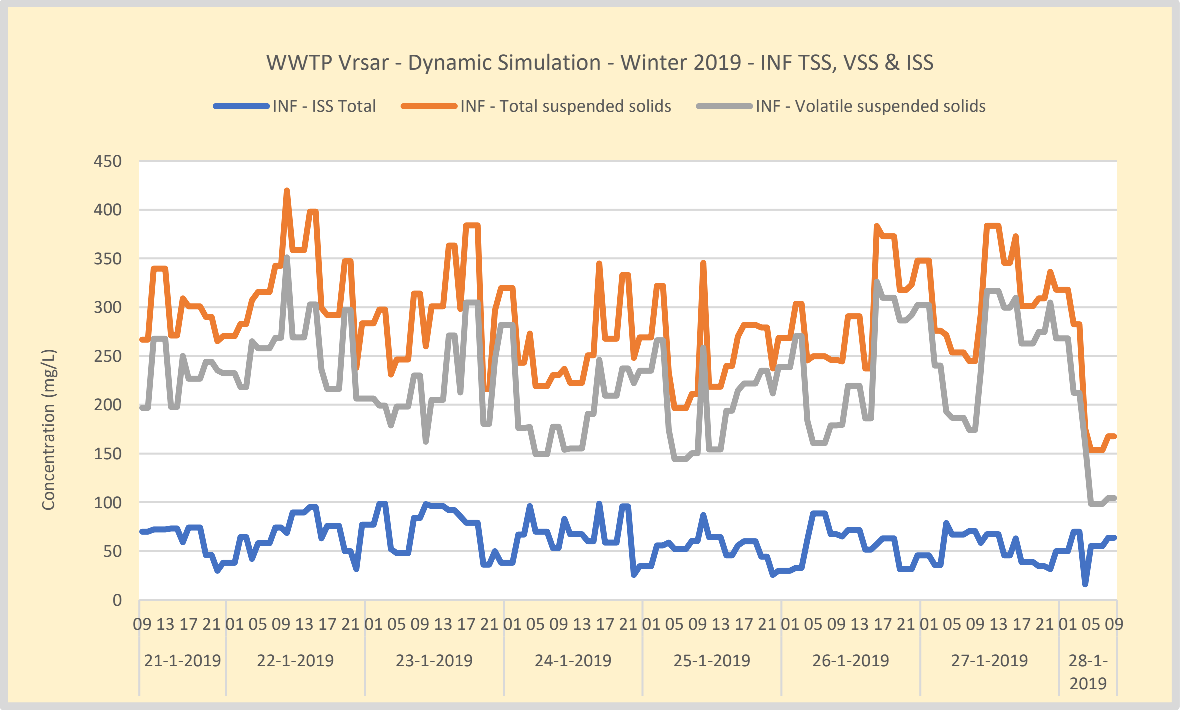


Figure 38. Dynamic Simulation – WWTP Vrsar – Winter 24-hour average TSS, VSS (organic particulate) and ISS (inorganic particulate) influent Concentration. The model input is the measured and reconstructed ISS concentration. VSS is calculated based on (constant) fractions determined in the influent specification. TSS is modelled as the sum of ISS and VSS. 28-01-2019 a major rain event occurred causing a sharp drop in the influent ISS concentration. No exceptional peaks are measured.

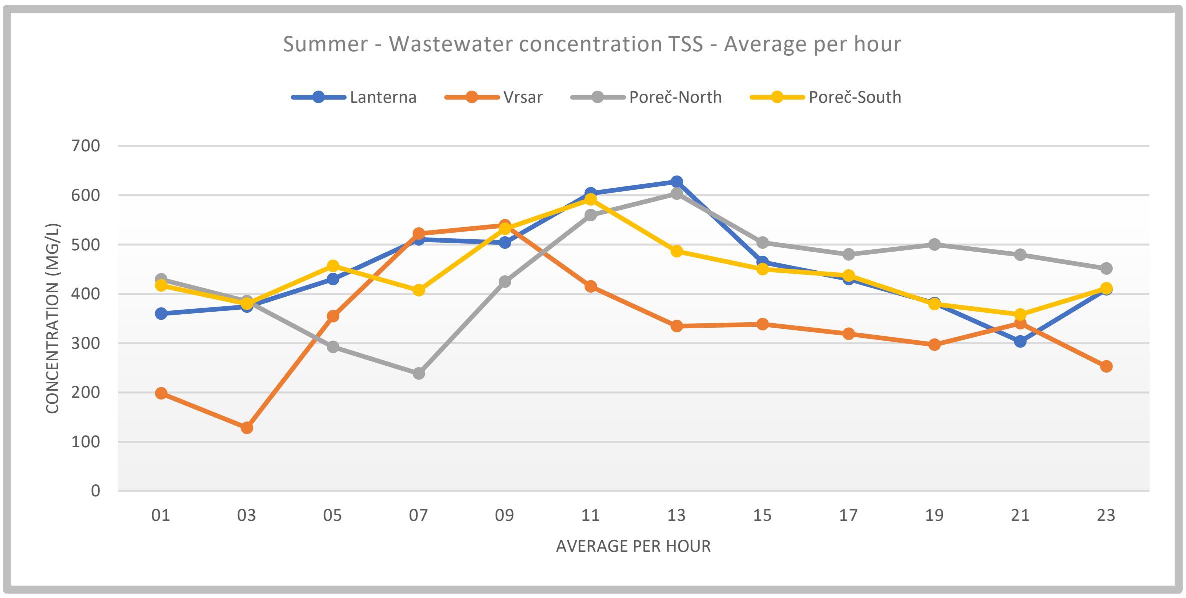
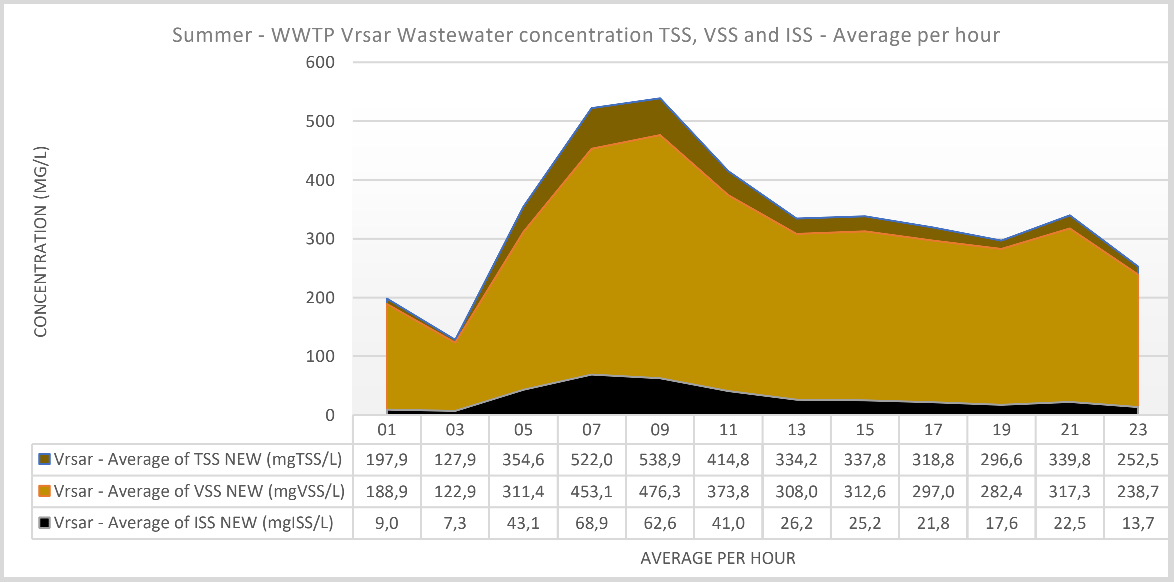


Figure 39. Summer – 24-hour average TSS Influent Concentration per WWTP.



	01	03	05	07	09	11	13	15	17	19	21	23
■ Vrsar - Average of TSS NEW (mgTSS/L)	197,9	127,9	354,6	522,0	538,9	414,8	334,2	337,8	318,8	296,6	339,8	252,5
■ Vrsar - Average of VSS NEW (mgVSS/L)	188,9	122,9	311,4	453,1	476,3	373,8	308,0	312,6	297,0	282,4	317,3	238,7
■ Vrsar - Average of ISS NEW (mgISS/L)	9,0	7,3	43,1	68,9	62,6	41,0	26,2	25,2	21,8	17,6	22,5	13,7

Figure 40. Summer – WWTP Vrsar 24-hour average TSS, VSS and ISS influent Concentration.

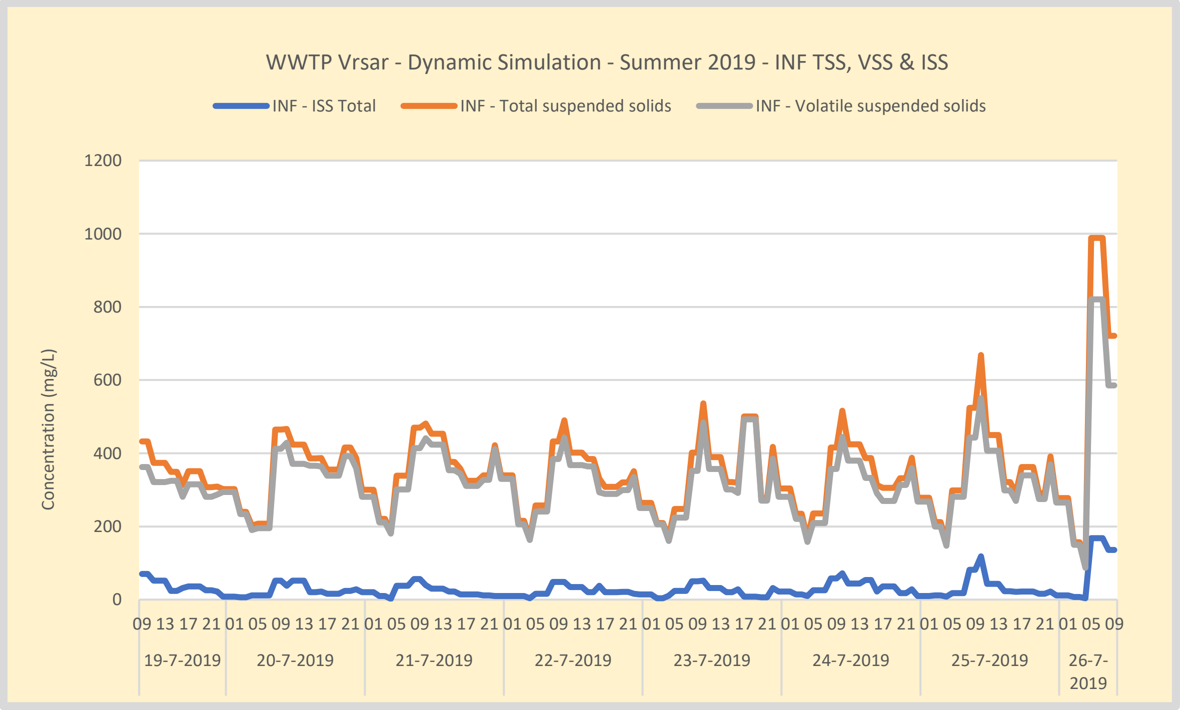
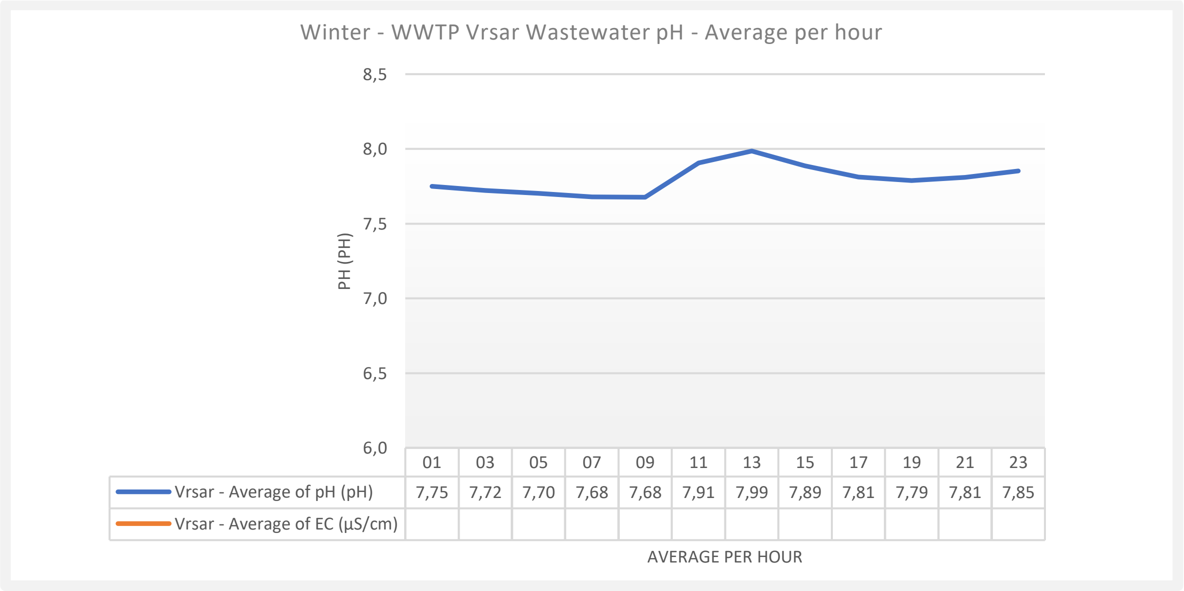


Figure 41. Dynamic Simulation – WWTP Vrsar – Summer 24-hour average TSS, VSS (organic particulate) and ISS (inorganic particulate) influent Concentration. The model input is the measured and reconstructed ISS concentration. VSS is calculated based on (constant) fractions determined in the influent specification. TSS is modelled as the sum of ISS and VSS. No rain occurred. Peak discharge of ISS occurred 25-7 and 26-7 in the morning.

5.9 pH influent measurement – winter and summer



	01	03	05	07	09	11	13	15	17	19	21	23
Vrsar - Average of pH (pH)	7,75	7,72	7,70	7,68	7,68	7,91	7,99	7,89	7,81	7,79	7,81	7,85
Vrsar - Average of EC (µS/cm)												

Figure 42. Winter – WWTP Vrsar 24-hour average pH influent measurement. During the winter period no conductivity was measured.

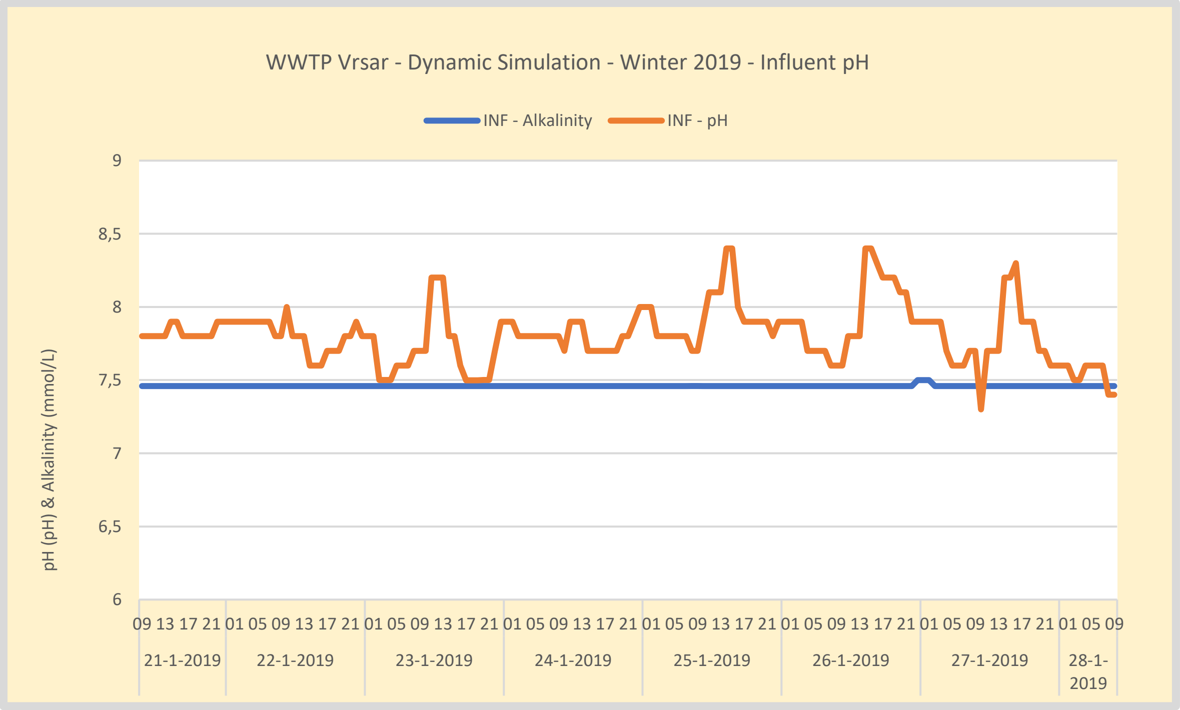
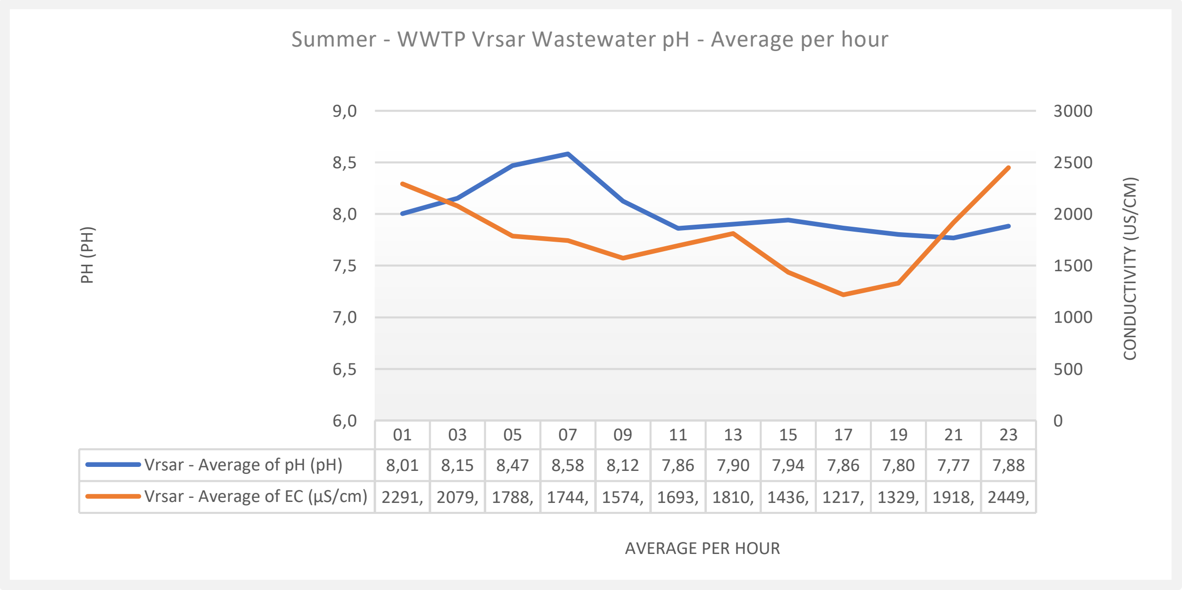


Figure 43. Dynamic Simulation – WWTP Vrsar – Winter 24-hour average influent pH measurement. pH is a dynamic model input. The alkalinity of wastewater is estimated from Poreč drinking water quality. 28-01-2019 a major rain event occurred.



	01	03	05	07	09	11	13	15	17	19	21	23
Vrsar - Average of pH (pH)	8,01	8,15	8,47	8,58	8,12	7,86	7,90	7,94	7,86	7,80	7,77	7,88
Vrsar - Average of EC (µS/cm)	2291,	2079,	1788,	1744,	1574,	1693,	1810,	1436,	1217,	1329,	1918,	2449,

Figure 44. Summer – WWTP Vrsar 24-hour average pH and conductivity influent measurement.

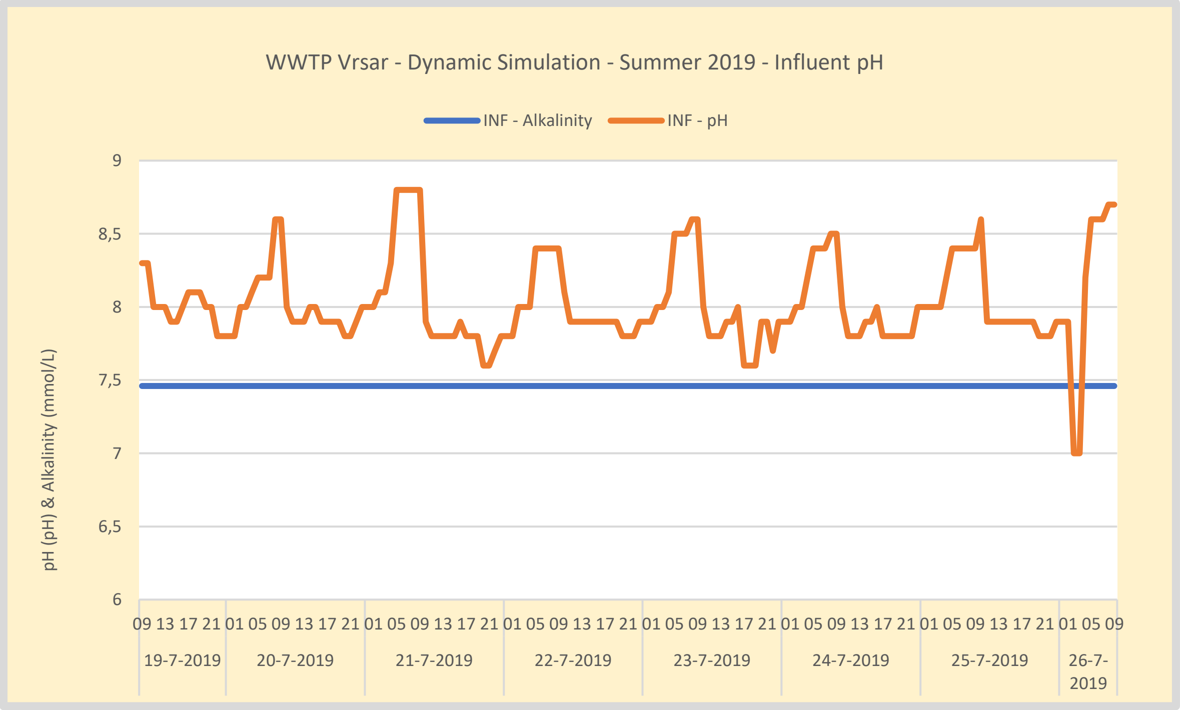
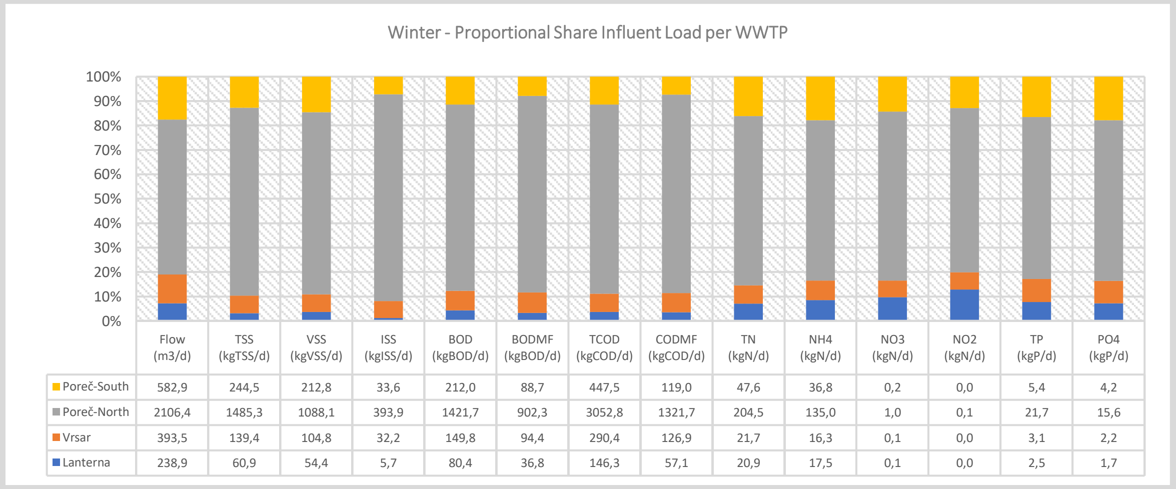


Figure 45. Dynamic Simulation – WWTP Vrsar – Summer 24-hour average influent pH measurement. pH is a dynamic model input. The alkalinity of wastewater is estimated from Poreč drinking water quality. 26-7-2019 a drop in the pH was measured coinciding with other concentration peak discharges indicating nondomestic discharge.

6 Influent loading profiles

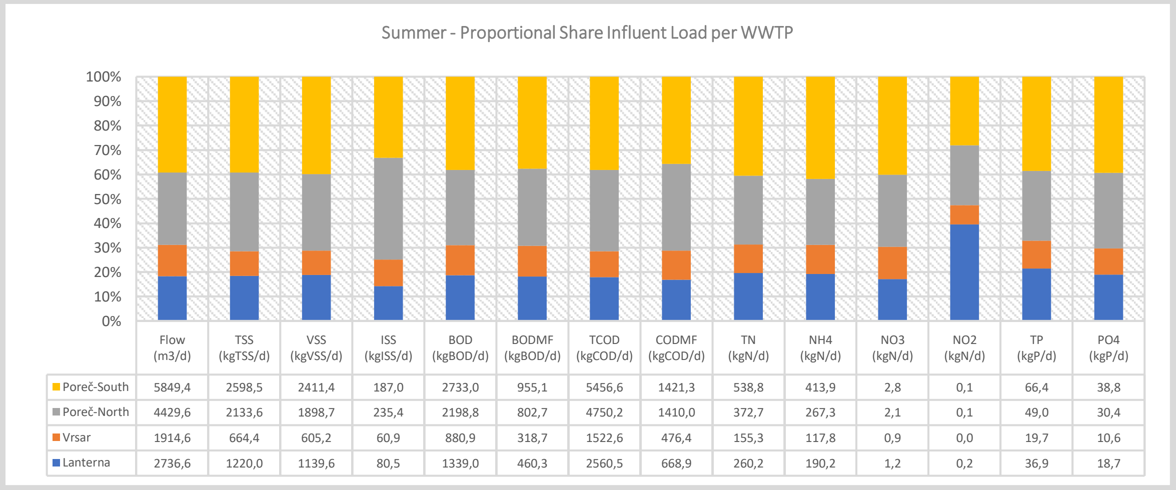
6.1 Average influent loads winter and summer period

The graphs below show daily average influent loads based on 7 days 24-hour, 2-hour interval continuous influent measurements measured under winter and summer conditions. The scale of graphs (0-100%) represents the influent fraction each WWTP treats relative to the total Poreč influent load. In the summer, all WWTP have a considerable higher loading. The increased summer loading of WWTP Poreč-North is approximately 200%, WWTP Vrsar 500%, and WWTP Poreč-South and Lanterna the wastewater increases approximately tenfold by 1000%.



	Flow (m3/d)	TSS (kgTSS/d)	VSS (kgVSS/d)	ISS (kgISS/d)	BOD (kgBOD/d)	BODMF (kgBOD/d)	TCOD (kgCOD/d)	CODMF (kgCOD/d)	TN (kgN/d)	NH4 (kgN/d)	NO3 (kgN/d)	NO2 (kgN/d)	TP (kgP/d)	PO4 (kgP/d)
🟨 Poreč-South	582,9	244,5	212,8	33,6	212,0	88,7	447,5	119,0	47,6	36,8	0,2	0,0	5,4	4,2
■ Poreč-North	2106,4	1485,3	1088,1	393,9	1421,7	902,3	3052,8	1321,7	204,5	135,0	1,0	0,1	21,7	15,6
🟧 Vrsar	393,5	139,4	104,8	32,2	149,8	94,4	290,4	126,9	21,7	16,3	0,1	0,0	3,1	2,2
🟦 Lanterna	238,9	60,9	54,4	5,7	80,4	36,8	146,3	57,1	20,9	17,5	0,1	0,0	2,5	1,7

Figure 46. Winter - Proportional Share Influent Load per WWTP.



	Flow (m3/d)	TSS (kgTSS/d)	VSS (kgVSS/d)	ISS (kgISS/d)	BOD (kgBOD/d)	BODMF (kgBOD/d)	TCOD (kgCOD/d)	CODMF (kgCOD/d)	TN (kgN/d)	NH4 (kgN/d)	NO3 (kgN/d)	NO2 (kgN/d)	TP (kgP/d)	PO4 (kgP/d)
🟨 Poreč-South	5849,4	2598,5	2411,4	187,0	2733,0	955,1	5456,6	1421,3	538,8	413,9	2,8	0,1	66,4	38,8
■ Poreč-North	4429,6	2133,6	1898,7	235,4	2198,8	802,7	4750,2	1410,0	372,7	267,3	2,1	0,1	49,0	30,4
🟧 Vrsar	1914,6	664,4	605,2	60,9	880,9	318,7	1522,6	476,4	155,3	117,8	0,9	0,0	19,7	10,6
🟦 Lanterna	2736,6	1220,0	1139,6	80,5	1339,0	460,3	2560,5	668,9	260,2	190,2	1,2	0,2	36,9	18,7

Figure 47. Summer - Proportional Share Influent Load per WWTP.

6.2 Influent COD 24-hour dynamic loading profile

Loading profiles typically follow the flow profiles with exception for periods where concentration peaks. The combined COD wastewater load for the Poreč area during low and high season is shown in the figures below. COD is partly particulate material and is transported more slowly through the sewer than soluble material. This is especially the case during low season and low sewage flow conditions. Compared to TN the morning COD peak typically is lower resulting in a more gradual loading pattern over the day. The measured COD loading profile is typical for domestic source. However, incidental COD peaks measured over the week indicate other sources (industrial or agricultural) also contribute to the sewage.

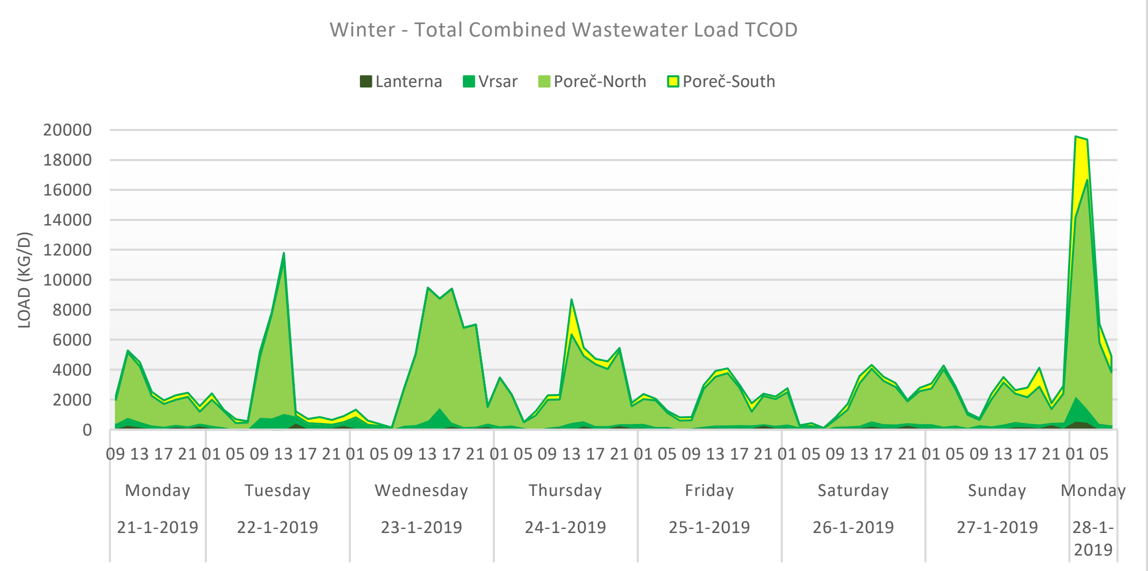
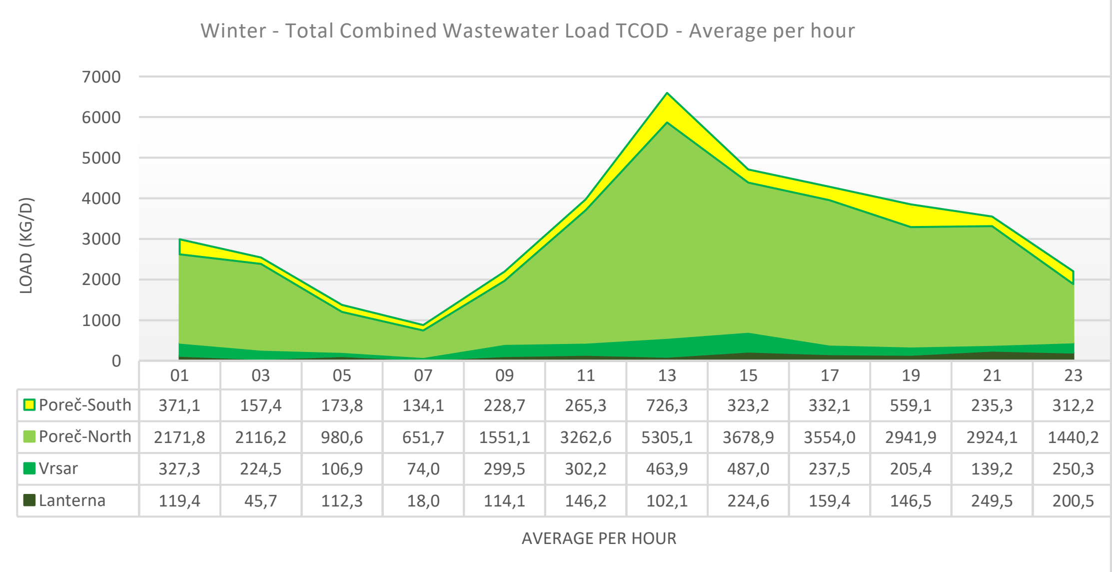


Figure 48. Winter – Sum of all WWTPs. Influent TCOD Load measured over 7 days. A rain event occurred Monday 28-01-2019. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟨 Poreč-South	371,1	157,4	173,8	134,1	228,7	265,3	726,3	323,2	332,1	559,1	235,3	312,2
🟩 Poreč-North	2171,8	2116,2	980,6	651,7	1551,1	3262,6	5305,1	3678,9	3554,0	2941,9	2924,1	1440,2
🟩 Vrsar	327,3	224,5	106,9	74,0	299,5	302,2	463,9	487,0	237,5	205,4	139,2	250,3
■ Lanterna	119,4	45,7	112,3	18,0	114,1	146,2	102,1	224,6	159,4	146,5	249,5	200,5

Figure 49. Winter – Sum of all WWTP’s. Hourly average influent TCOD Loads based on 7 measurement days, excluding rain event Monday 28-01-2019. This data is used to reconstruct missing data points in the 7-day measurements.

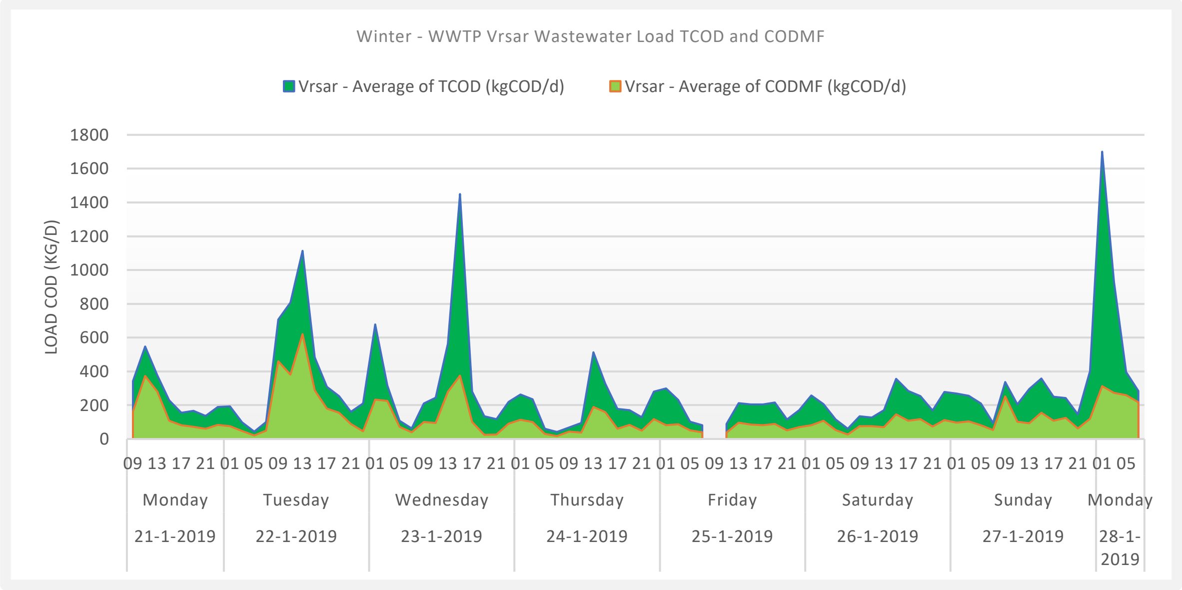
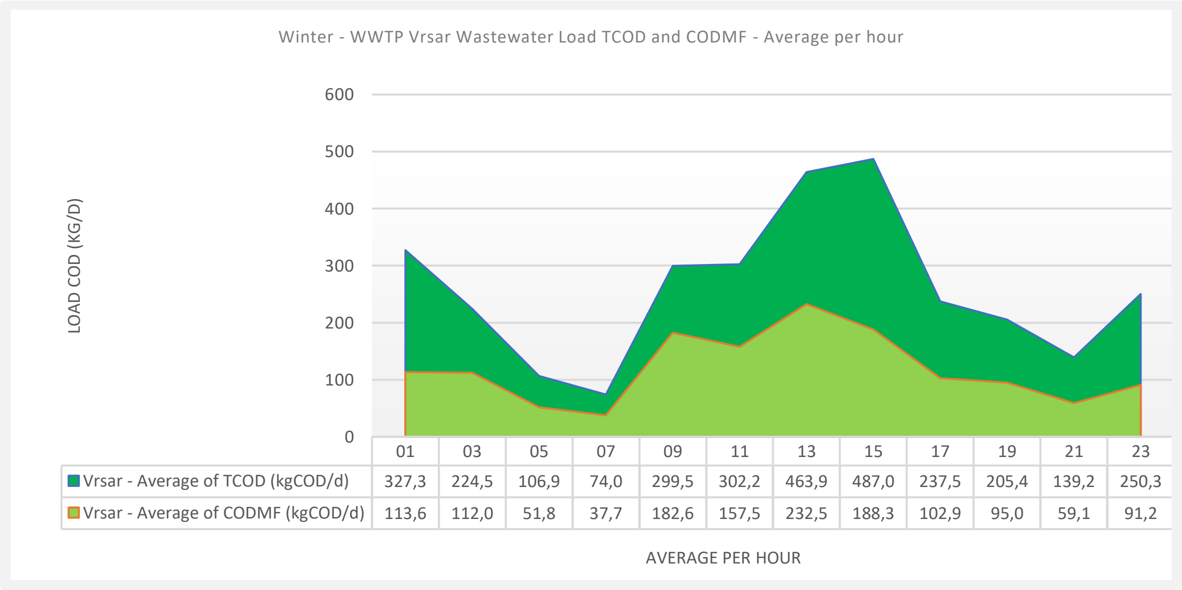


Figure 50. Winter – WWTP Vrsar Influent Total and filtered COD Loads based on 7 measurement days. A rain event occurred Monday 28-01-2019. For the model input missing data points (25-1) are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟩 Vrsar - Average of TCOD (kgCOD/d)	327,3	224,5	106,9	74,0	299,5	302,2	463,9	487,0	237,5	205,4	139,2	250,3
🟩 Vrsar - Average of CODMF (kgCOD/d)	113,6	112,0	51,8	37,7	182,6	157,5	232,5	188,3	102,9	95,0	59,1	91,2

Figure 51. Winter – WWTP Vrsar hourly average dry weather influent loads of total and filtered COD, based on 7 measurement days, excluding the rain event Monday 28-01-2019. This data is used to reconstruct missing data points in 7-day measurement series.

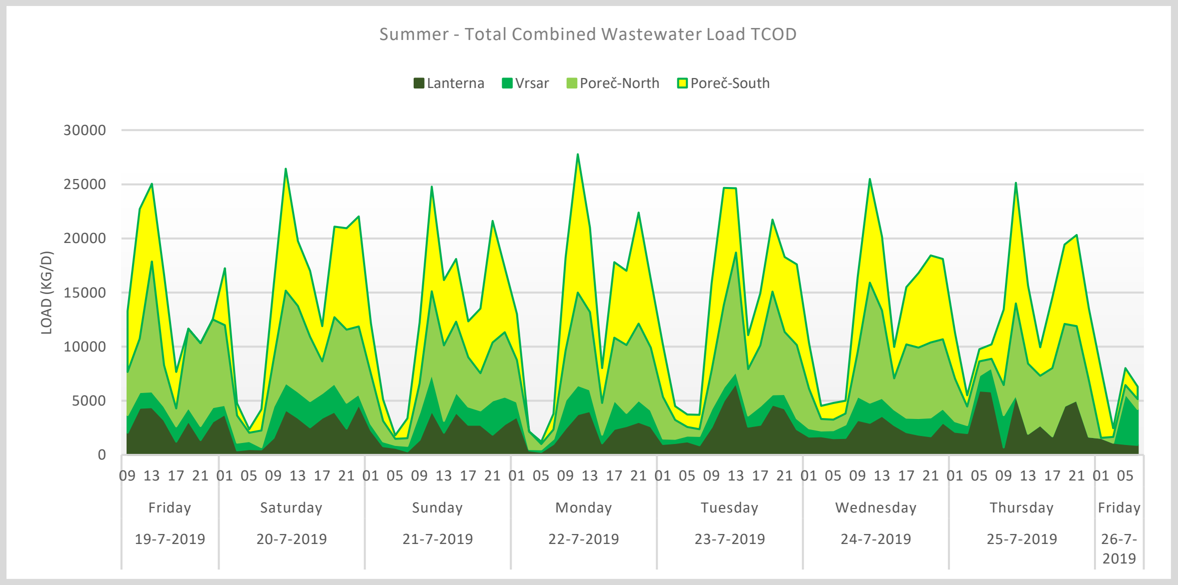
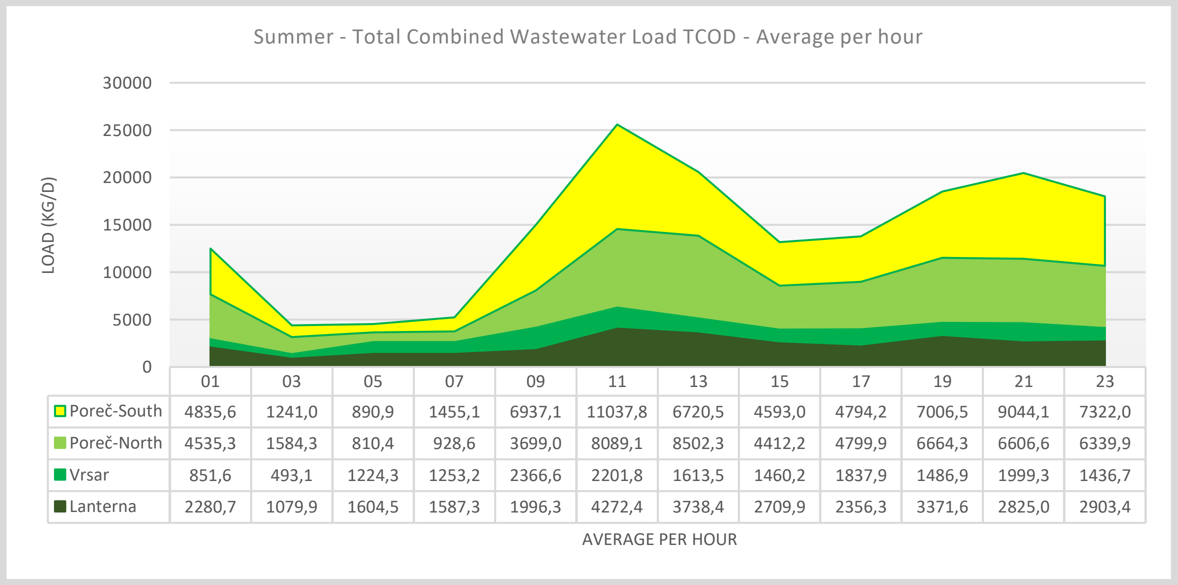


Figure 52. Summer – Sum of all WWTPs. Influent TCOD Load measured over 7 days. No rain events occurred during the measurement period. For the model input missing data points are reconstructed based on the hourly average dry weather load. The profile is typical for domestic source. No rain occurred. Monday seems to have slightly higher load which could be related to hotel room cleaning.



	01	03	05	07	09	11	13	15	17	19	21	23
Poreč-South	4835,6	1241,0	890,9	1455,1	6937,1	11037,8	6720,5	4593,0	4794,2	7006,5	9044,1	7322,0
Poreč-North	4535,3	1584,3	810,4	928,6	3699,0	8089,1	8502,3	4412,2	4799,9	6664,3	6606,6	6339,9
Vrsar	851,6	493,1	1224,3	1253,2	2366,6	2201,8	1613,5	1460,2	1837,9	1486,9	1999,3	1436,7
Lanterna	2280,7	1079,9	1604,5	1587,3	1996,3	4272,4	3738,4	2709,9	2356,3	3371,6	2825,0	2903,4

Figure 53. Summer – Sum of all WWTP's. Hourly average influent TCOD Loads based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in the 7-day measurements. During high flow conditions the peak shifts from 13:00 to 11:00 and a second peak is appearing around 21:00. The profile is typical for domestical source.

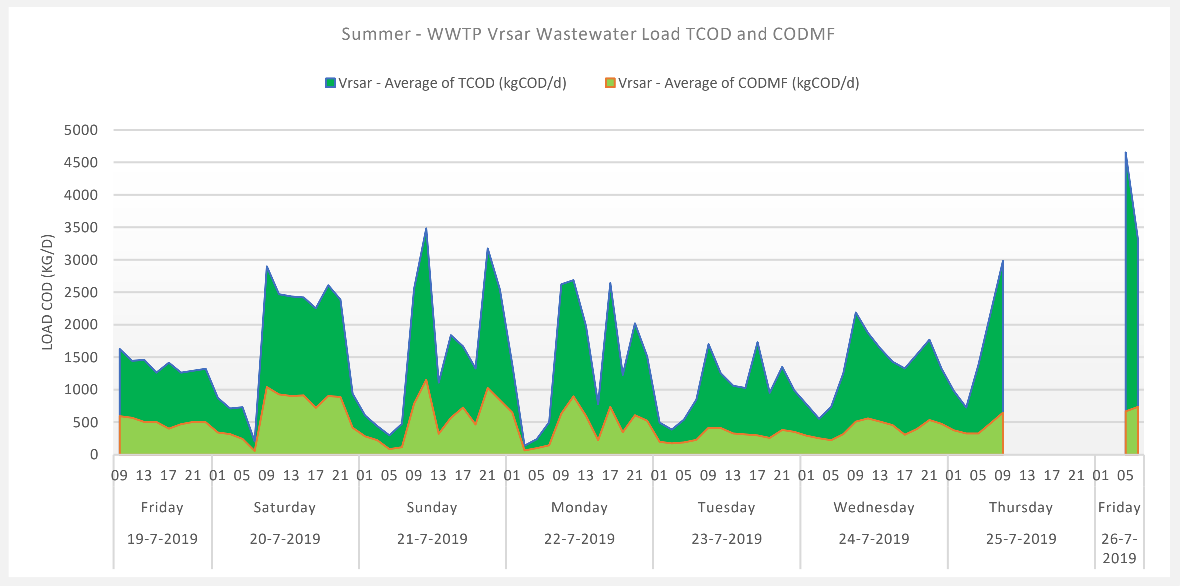
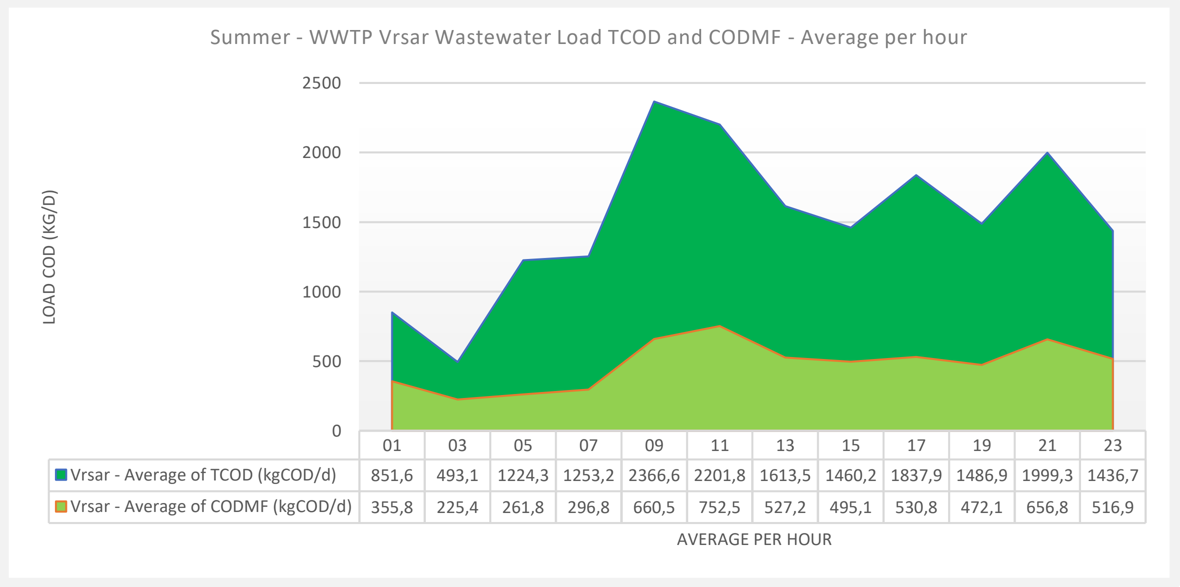


Figure 54. Summer - WWTP Vrsar Wastewater Load TCOD and CODMF. No rain events occurred during the measurement period. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟩 Vrsar - Average of TCOD (kgCOD/d)	851,6	493,1	1224,3	1253,2	2366,6	2201,8	1613,5	1460,2	1837,9	1486,9	1999,3	1436,7
🟩 Vrsar - Average of CODMF (kgCOD/d)	355,8	225,4	261,8	296,8	660,5	752,5	527,2	495,1	530,8	472,1	656,8	516,9

Figure 55. Winter – WWTP Vrsar hourly average dry weather influent loads of total and filtered COD, based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in 7-day measurement series.

6.3 Influent Nitrogen 24-hour dynamic loading profile

The nitrogen (TN) loading is presented in the graphs below. The data shows a typical domestical source. A large fraction of TN is soluble ammonium which is easily transported in the sewer. This typically results in a high peak of ammonium in the morning between 11:00 and 13:00, depending on the flow and sewer residence time.

Ammonium peaks result in a high oxygen demand at the WWTP because of the nitrification process. Under peak conditions, especially when the wastewater is warm, aeration can be come limiting.

No presence of nitrate was measured in the sewage. Appearance of nitrate in closed sewers could indicate groundwater infiltration.

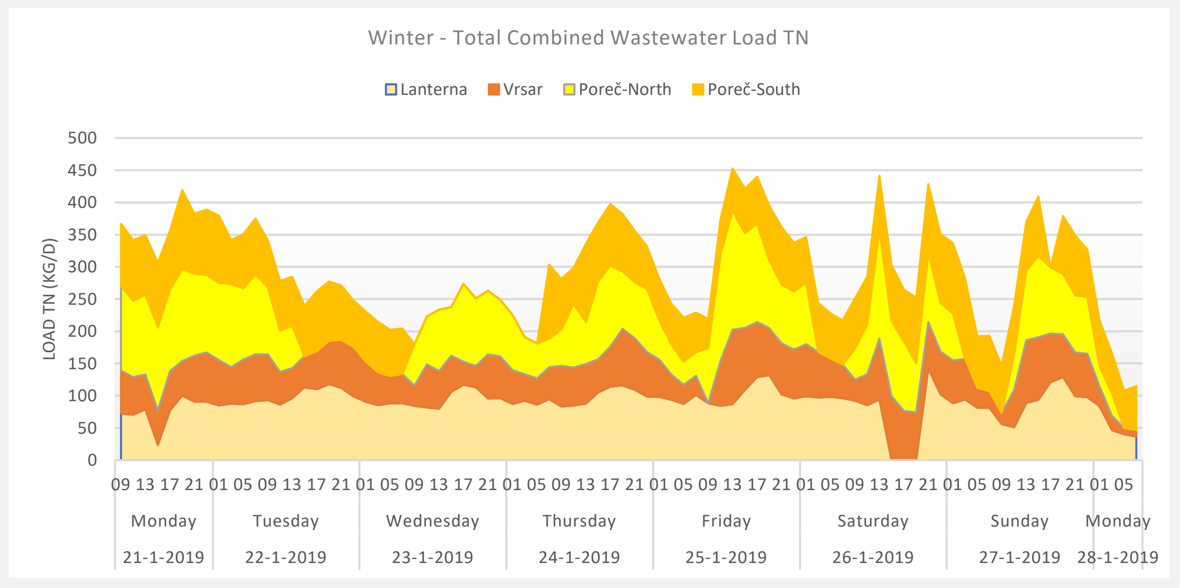
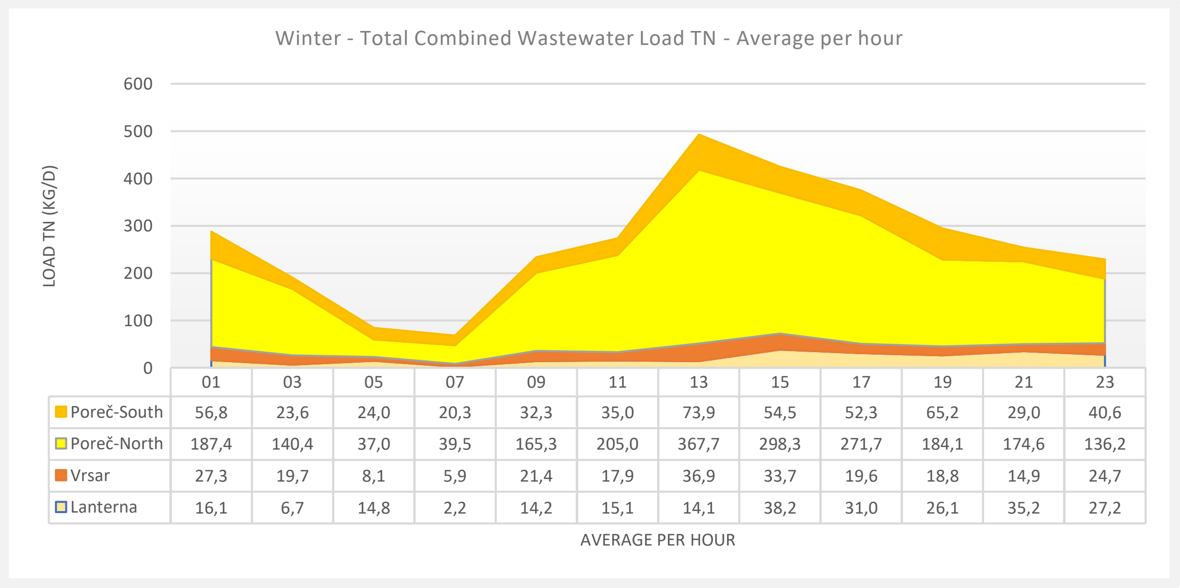


Figure 56. Winter – Sum of all WWTPs. Influent TN Load measured over 7 days. A rain event occurred Monday 28-01-2019. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
Poreč-South	56,8	23,6	24,0	20,3	32,3	35,0	73,9	54,5	52,3	65,2	29,0	40,6
Poreč-North	187,4	140,4	37,0	39,5	165,3	205,0	367,7	298,3	271,7	184,1	174,6	136,2
Vrsar	27,3	19,7	8,1	5,9	21,4	17,9	36,9	33,7	19,6	18,8	14,9	24,7
Lanterna	16,1	6,7	14,8	2,2	14,2	15,1	14,1	38,2	31,0	26,1	35,2	27,2

Figure 57. Winter – Sum of all WWTP’s. Hourly average influent TN Loads based on 7 measurement days, excluding rain event Monday 28-01-2019. This data is used to reconstruct missing data points in the 7-day measurements.

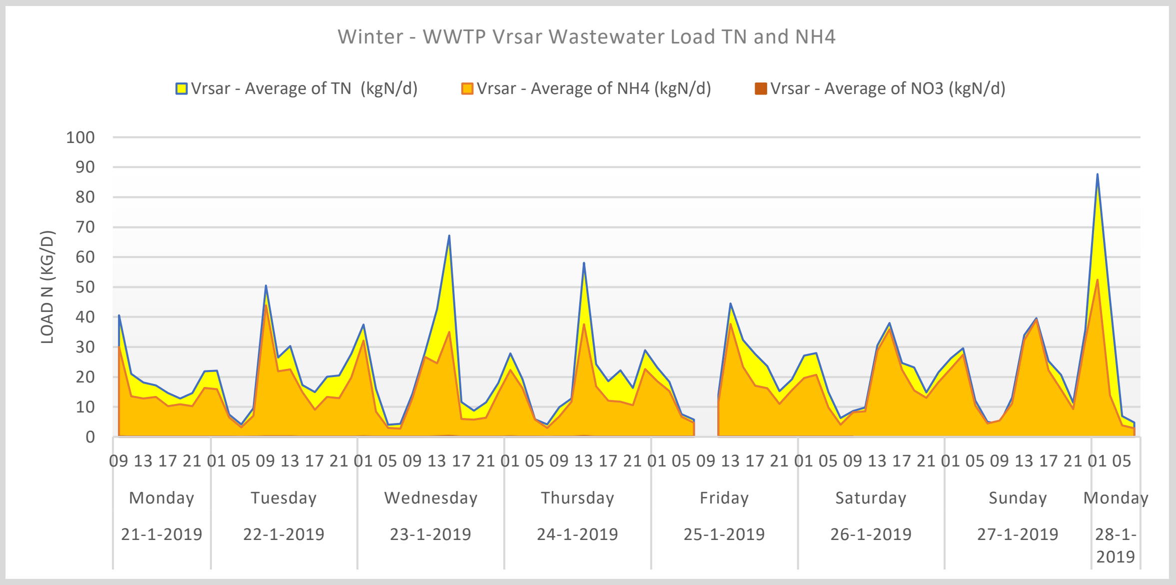
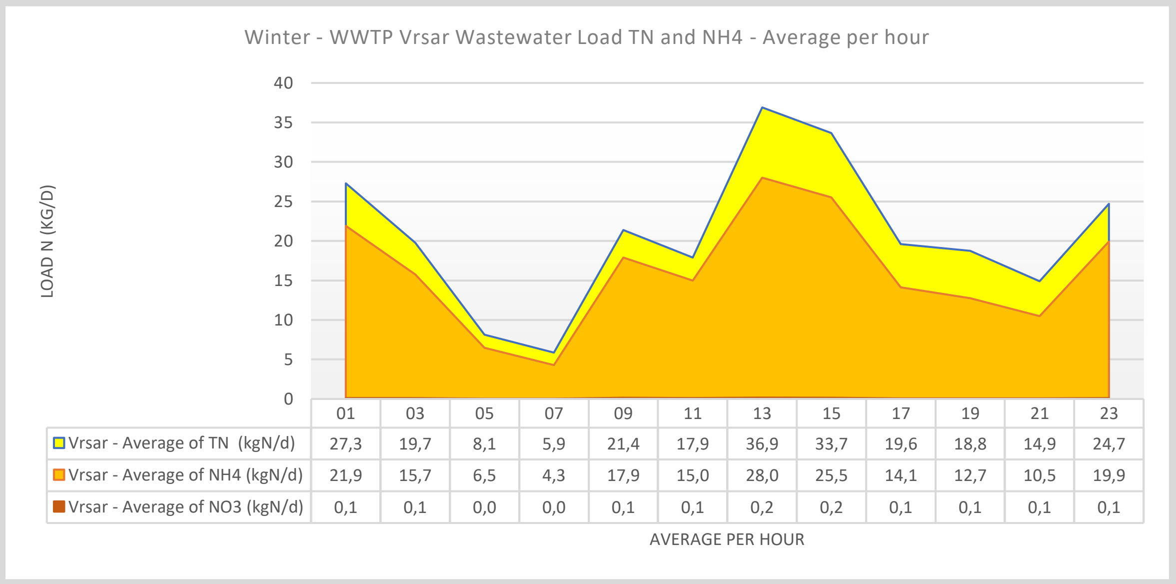


Figure 58. Winter – WWTP Vrsar Influent TN, NH4 and NO3 Loads based on 7 measurement days. A rain event occurred Monday 28-01-2019. For the model input missing data points (25-1) are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟨 Vrsar - Average of TN (kgN/d)	27,3	19,7	8,1	5,9	21,4	17,9	36,9	33,7	19,6	18,8	14,9	24,7
🟧 Vrsar - Average of NH4 (kgN/d)	21,9	15,7	6,5	4,3	17,9	15,0	28,0	25,5	14,1	12,7	10,5	19,9
🟫 Vrsar - Average of NO3 (kgN/d)	0,1	0,1	0,0	0,0	0,1	0,1	0,2	0,2	0,1	0,1	0,1	0,1

Figure 59. Winter – WWTP Vrsar hourly average dry weather influent loads TN, NH4 and NO3, based on 7 measurement days, excluding the rain event Monday 28-01-2019. This data is used to reconstruct missing data points in 7-day measurement series.

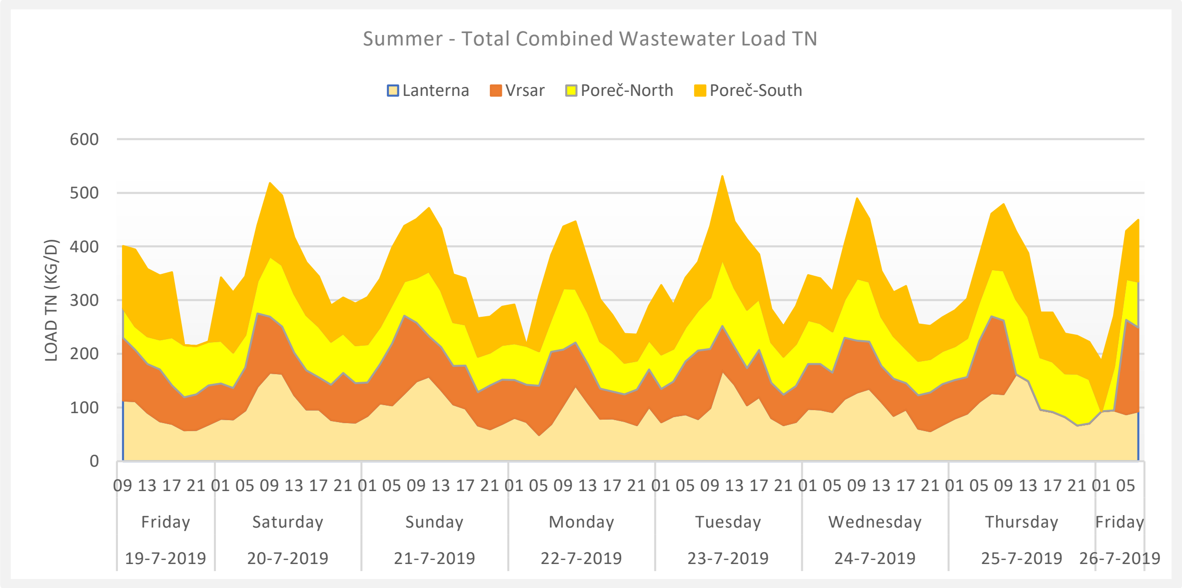
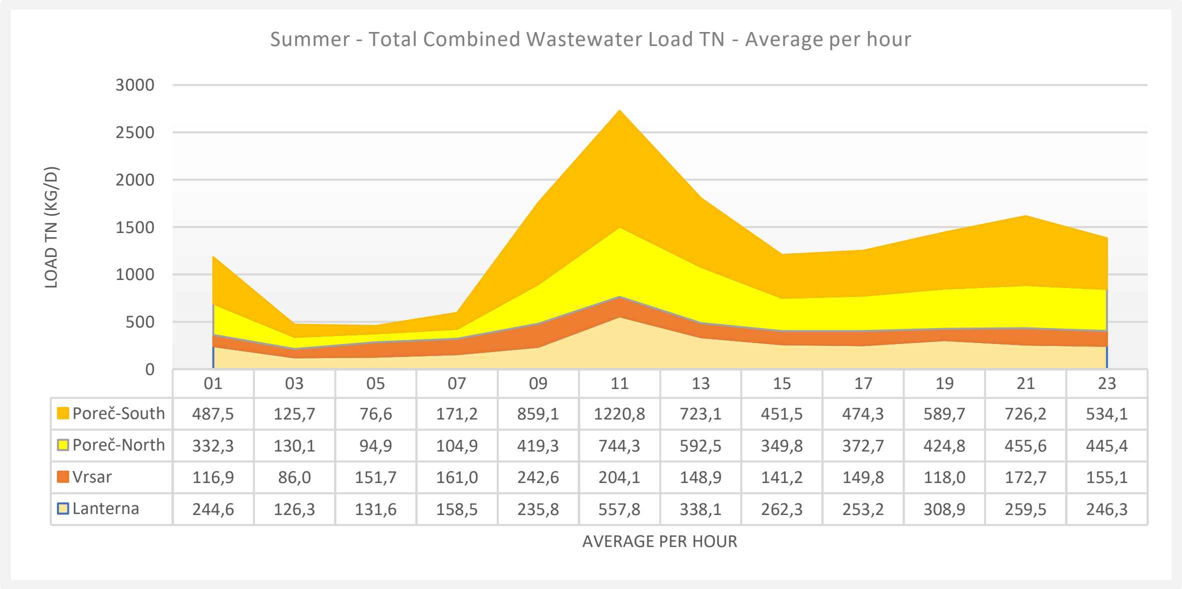


Figure 60. Summer – Sum of all WWTPs. Influent TN Load measured over 7 days. No rain events occurred during the measurement period. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟨 Poreč-South	487,5	125,7	76,6	171,2	859,1	1220,8	723,1	451,5	474,3	589,7	726,2	534,1
🟨 Poreč-North	332,3	130,1	94,9	104,9	419,3	744,3	592,5	349,8	372,7	424,8	455,6	445,4
🟧 Vrsar	116,9	86,0	151,7	161,0	242,6	204,1	148,9	141,2	149,8	118,0	172,7	155,1
☐ Lanterna	244,6	126,3	131,6	158,5	235,8	557,8	338,1	262,3	253,2	308,9	259,5	246,3

Figure 61. Summer – Sum of all WWTP's. Hourly average influent TN Loads based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in the 7-day measurements.

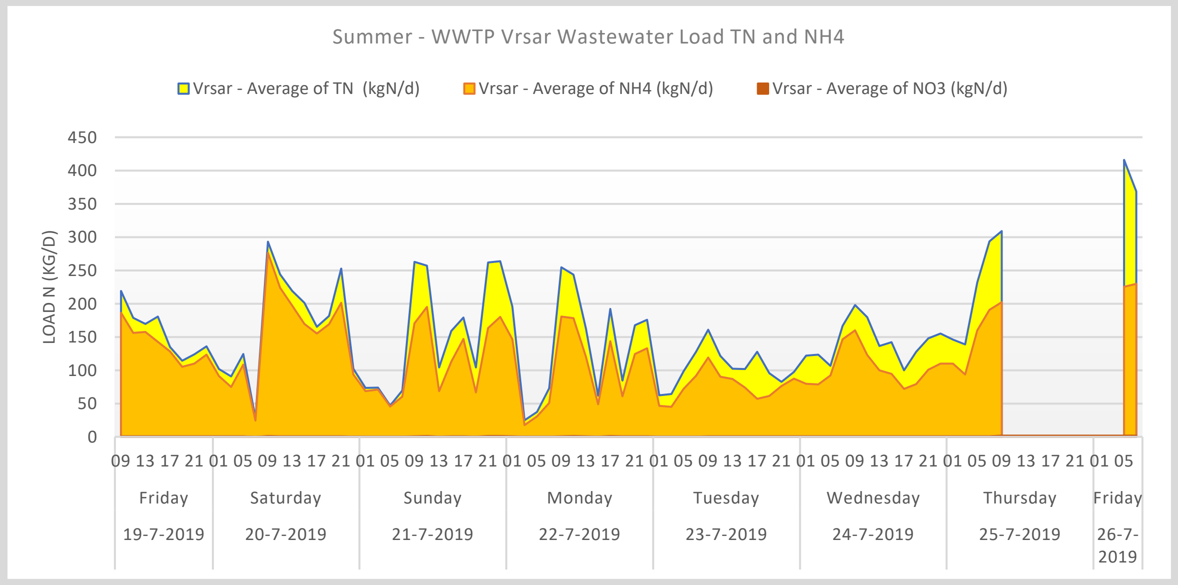
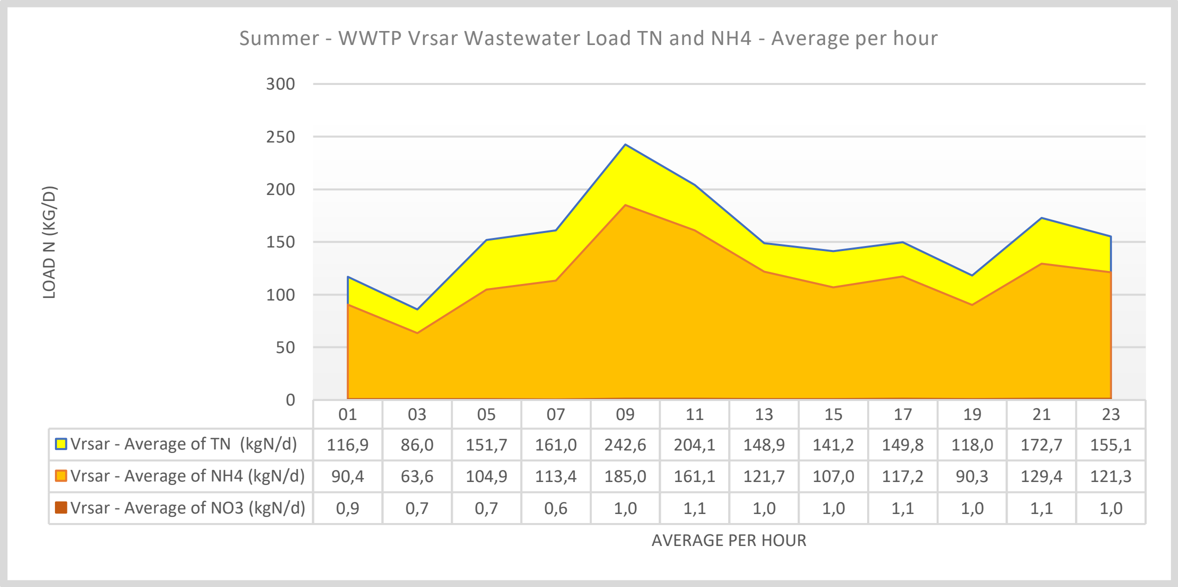


Figure 62. Summer - WWTP Vrsar Wastewater Load TN, NH4 and NO3. No rain events occurred during the measurement period. For the model input missing data points (25-7) are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟨 Vrsar - Average of TN (kgN/d)	116,9	86,0	151,7	161,0	242,6	204,1	148,9	141,2	149,8	118,0	172,7	155,1
🟧 Vrsar - Average of NH4 (kgN/d)	90,4	63,6	104,9	113,4	185,0	161,1	121,7	107,0	117,2	90,3	129,4	121,3
🟫 Vrsar - Average of NO3 (kgN/d)	0,9	0,7	0,7	0,6	1,0	1,1	1,0	1,0	1,1	1,0	1,1	1,0

Figure 63. Winter – WWTP Vrsar hourly average dry weather influent loads of TN, NH4 and NO3, based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in 7-day measurement series.

6.4 Influent Phosphorus 24-hour dynamic loading profile

The phosphorus loading is presented in the graphs below. Phosphorus consists largely of a soluble ortho-phosphate fraction which is easily transported in the sewer system. A smaller fraction is related to particulate organic material (particulate COD). Orthophosphate originates from domestic source in the form of urine. Phosphate often resembles the ammonium profile, peaking between 11:00 and 13:00.

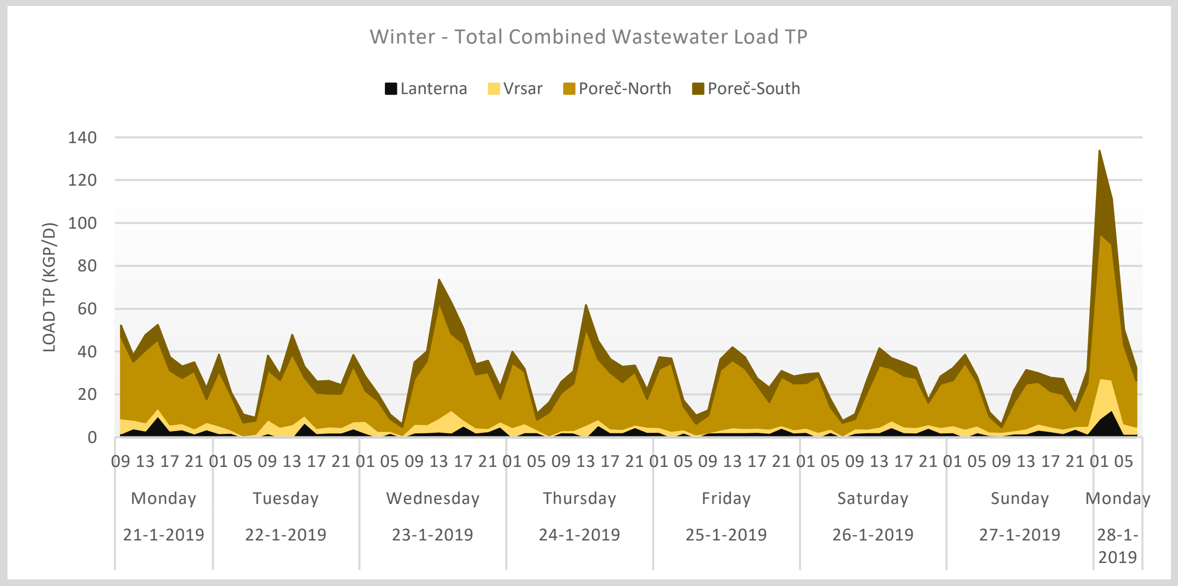
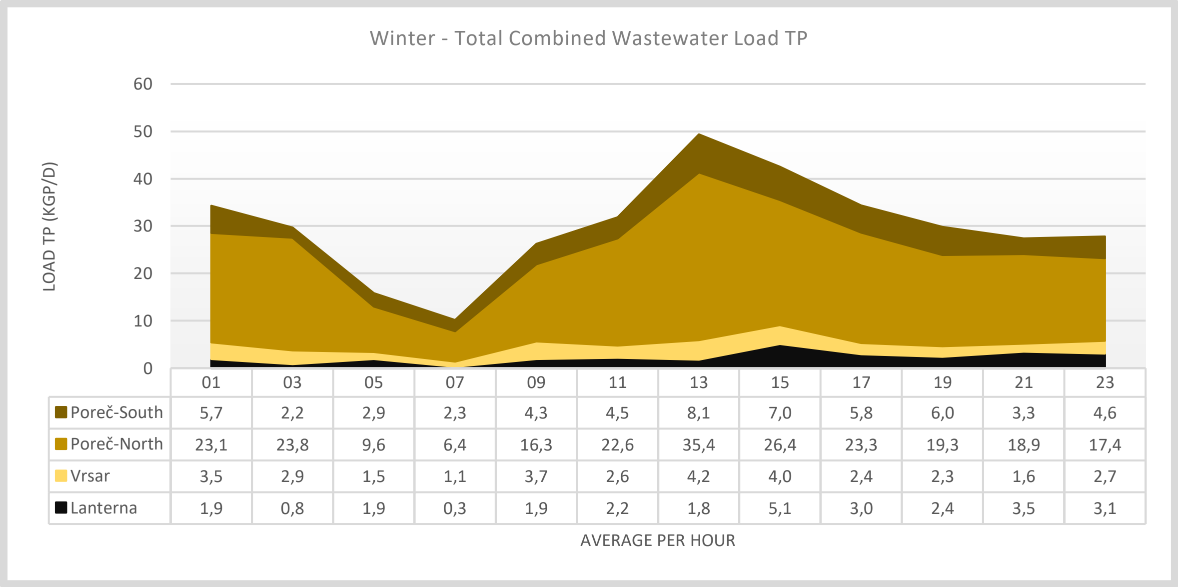


Figure 64. Winter – Sum of all WWTPs. Influent TP Load measured over 7 days. A rain event occurred Monday 28-01-2019. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
■ Poreč-South	5,7	2,2	2,9	2,3	4,3	4,5	8,1	7,0	5,8	6,0	3,3	4,6
■ Poreč-North	23,1	23,8	9,6	6,4	16,3	22,6	35,4	26,4	23,3	19,3	18,9	17,4
■ Vrsar	3,5	2,9	1,5	1,1	3,7	2,6	4,2	4,0	2,4	2,3	1,6	2,7
■ Lanterna	1,9	0,8	1,9	0,3	1,9	2,2	1,8	5,1	3,0	2,4	3,5	3,1

Figure 65. Winter – Sum of all WWTP’s. Hourly average influent TP Load based on 7 measurement days, excluding rain event Monday 28-01-2019. This data is used to reconstruct missing data points in the 7-day measurements.

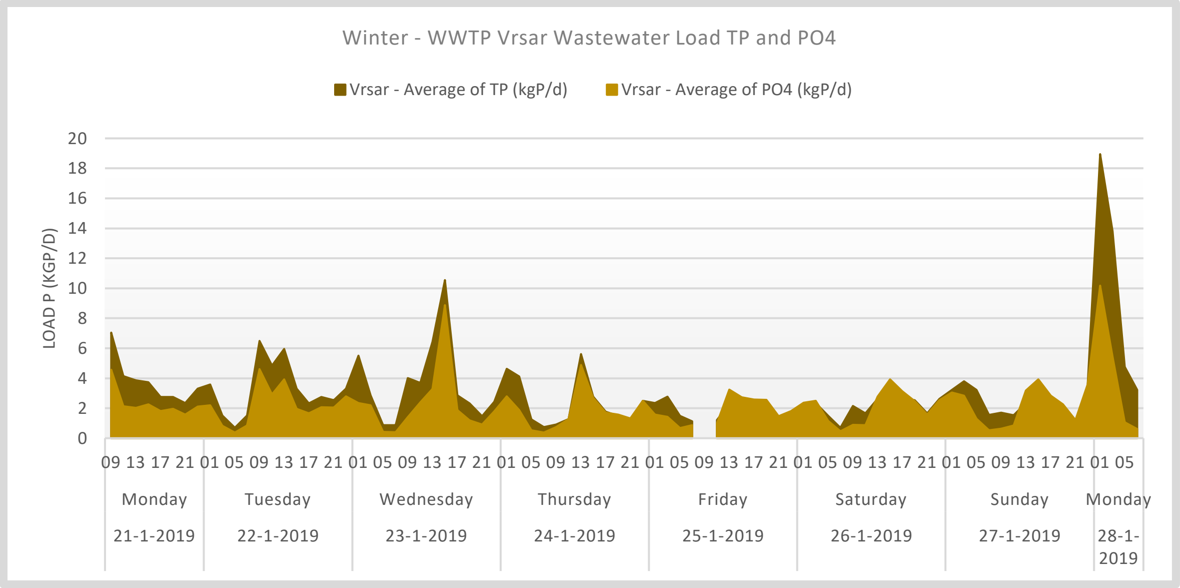
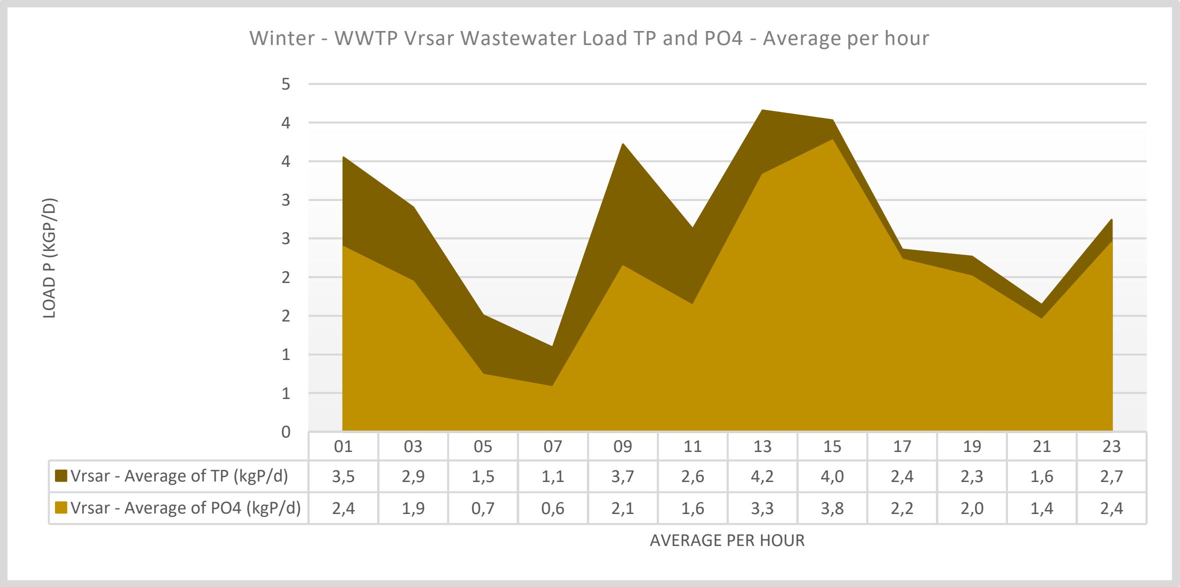


Figure 66. Winter – WWTP Vrsar Influent TP and PO4 Loads based on 7 measurement days. A rain event occurred Monday 28-01-2019. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
Vrsar - Average of TP (kgP/d)	3,5	2,9	1,5	1,1	3,7	2,6	4,2	4,0	2,4	2,3	1,6	2,7
Vrsar - Average of PO4 (kgP/d)	2,4	1,9	0,7	0,6	2,1	1,6	3,3	3,8	2,2	2,0	1,4	2,4

Figure 67. Winter – WWTP Vrsar hourly average influent loads TP and PO4, based on 7 measurement days, excluding the rain event Monday 28-01-2019. This data is used to reconstruct missing data points in 7-day measurement series.

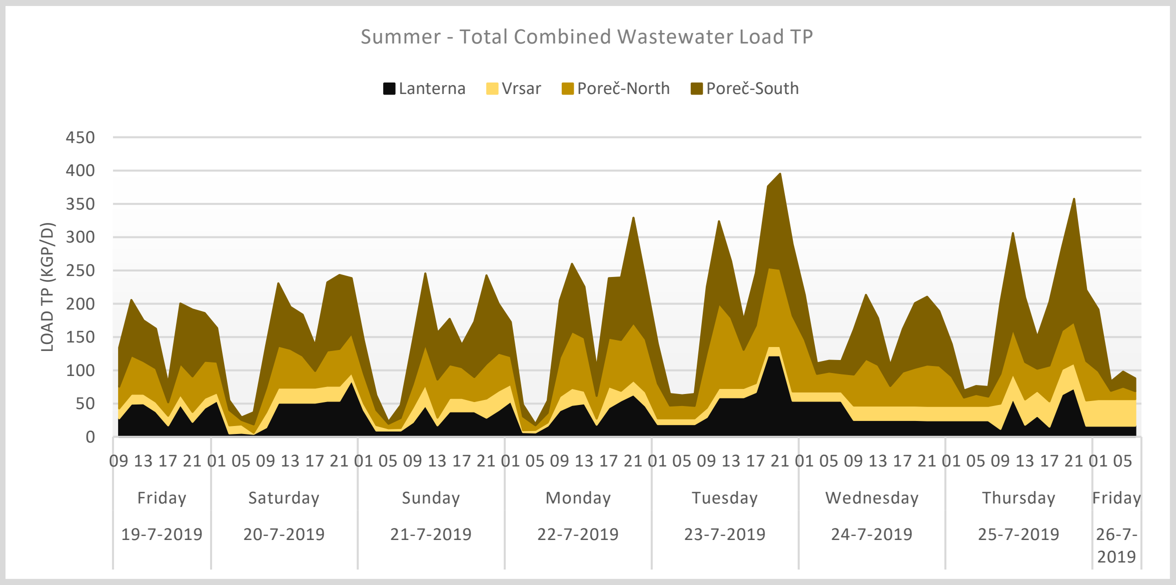
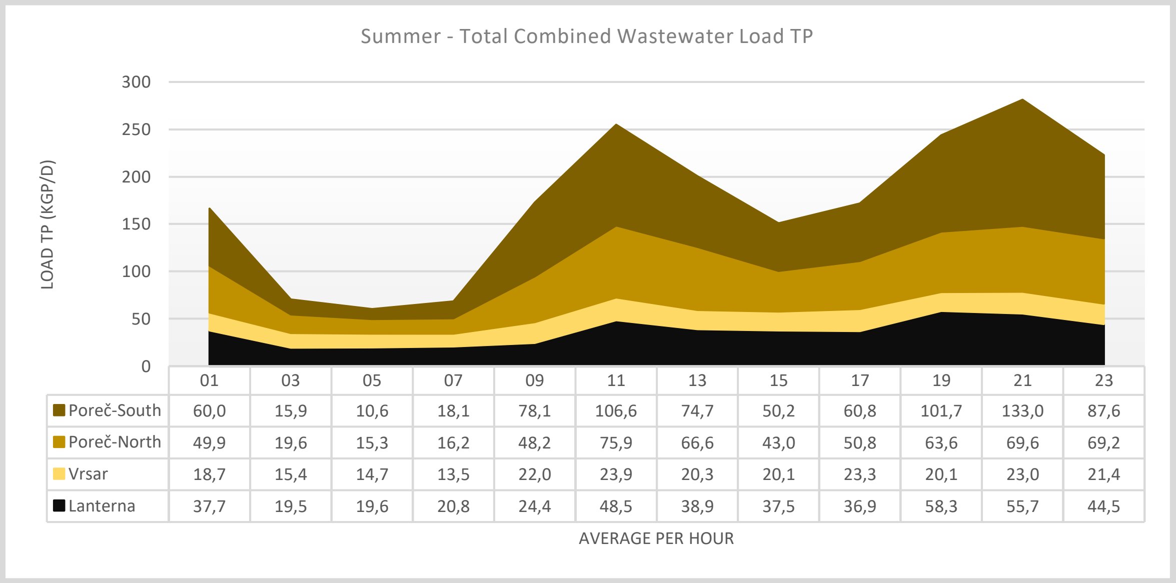


Figure 68. Summer – Sum of all WWTPs. Influent TP Load measured over 7 days. No rain events occurred during the measurement period. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
Poreč-South	60,0	15,9	10,6	18,1	78,1	106,6	74,7	50,2	60,8	101,7	133,0	87,6
Poreč-North	49,9	19,6	15,3	16,2	48,2	75,9	66,6	43,0	50,8	63,6	69,6	69,2
Vrsar	18,7	15,4	14,7	13,5	22,0	23,9	20,3	20,1	23,3	20,1	23,0	21,4
Lanterna	37,7	19,5	19,6	20,8	24,4	48,5	38,9	37,5	36,9	58,3	55,7	44,5

Figure 69. Summer – Sum of all WWTP's. Hourly average influent TP Loads based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in the 7-day measurements.

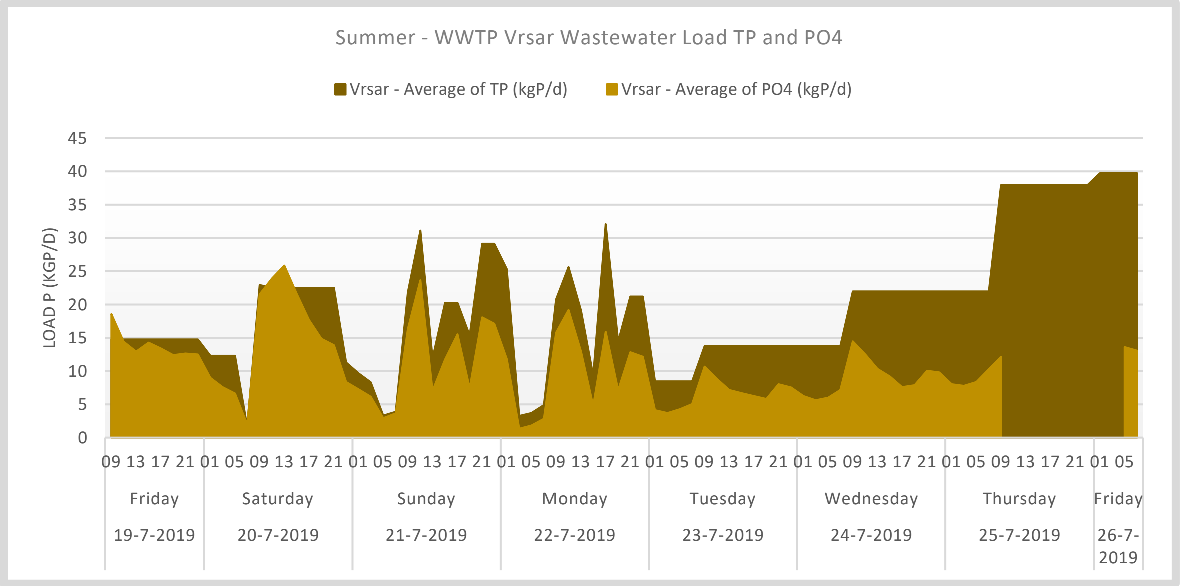
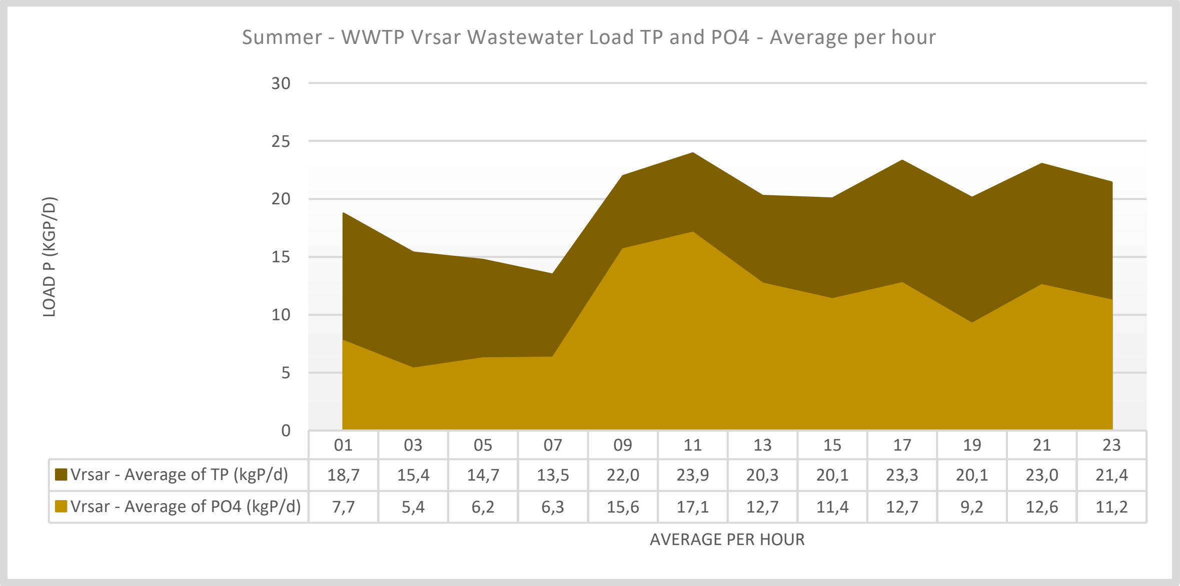


Figure 70. Summer - WWTP Vrsar Wastewater Loads TP and PO4. No rain events occurred during the measurement period. For the model input missing data points are reconstructed based on the hourly average dry weather load. Summer load is affected by the unusual flow profile resulting in a large peak load 25 and 26-7..



	01	03	05	07	09	11	13	15	17	19	21	23
■ Vrsar - Average of TP (kgP/d)	18,7	15,4	14,7	13,5	22,0	23,9	20,3	20,1	23,3	20,1	23,0	21,4
■ Vrsar - Average of PO4 (kgP/d)	7,7	5,4	6,2	6,3	15,6	17,1	12,7	11,4	12,7	9,2	12,6	11,2

Figure 71. Summer – WWTP Vrsar hourly average influent loads TP and PO4, based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in 7-day measurement series.

6.5 Influent Total Suspended Solids 24-hour dynamic loading profile

The loading of particulate material (total suspended solids) is presented in the graphs below. Particulate material typically has a longer transportation time in the sewer. Solid materials will settle in the sewer, especially during dry weather and low nighty flow. Therefore, at low flow conditions, TSS concentration measurements usually are underestimated by 15-25%. During peak flow or rain events, the settled TSS fraction is stirred up and transported to the WWTP. Under these conditions, concentration measurements are generally overestimated. As a result, during low season and low flow conditions, usually only one TSS peak is measured during the day, while during high season two peaks are measured: One in the morning and one in the evening coinciding with the flow dynamics.

TSS consists largely of organic material (volatile suspended solids or VSS). The inorganic fraction (ISS) is typically 6-9%. TSS is typically organic material from domestic source and collected from the pavement during rain events. Typically, half of the domestic TSS source is cellulose originating from toilet paper. Industrial and agricultural TSS usually are fibers with a low biodegradability.

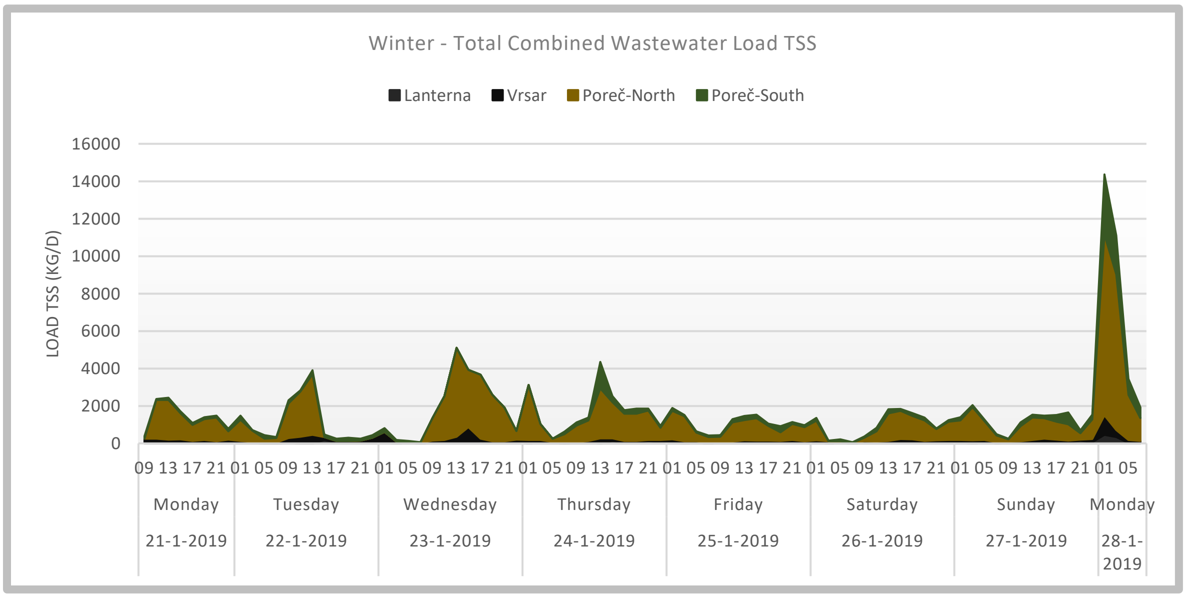
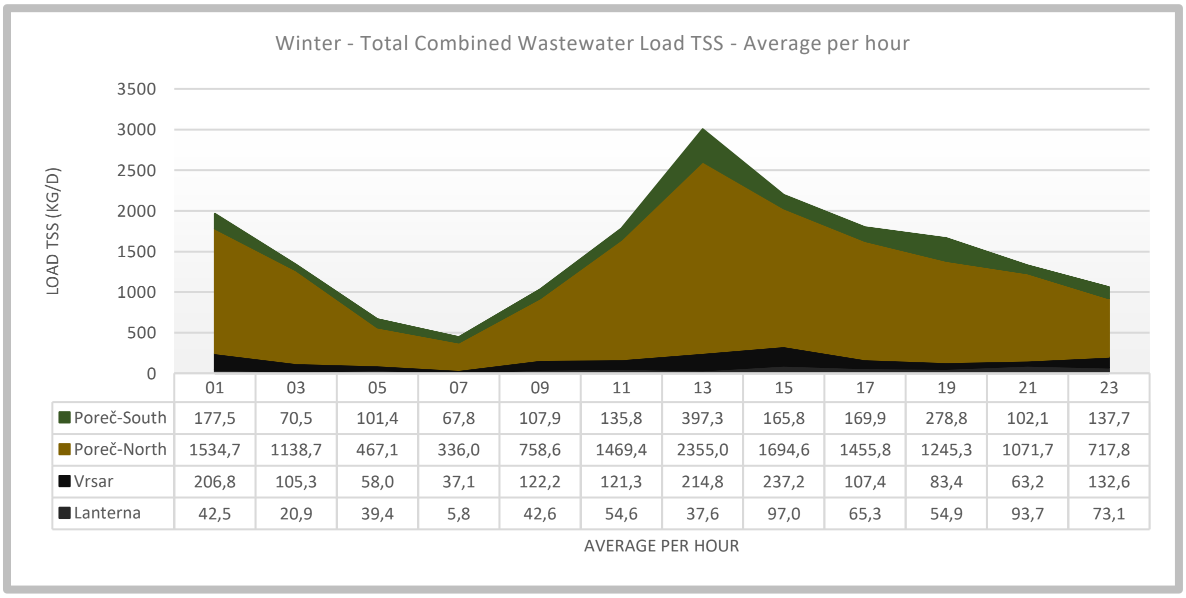


Figure 72. Winter – Sum of all WWTPs. Influent TSS Load measured over 7 days. A rain event occurred Monday 28-01-2019. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
■ Poreč-South	177,5	70,5	101,4	67,8	107,9	135,8	397,3	165,8	169,9	278,8	102,1	137,7
■ Poreč-North	1534,7	1138,7	467,1	336,0	758,6	1469,4	2355,0	1694,6	1455,8	1245,3	1071,7	717,8
■ Vrsar	206,8	105,3	58,0	37,1	122,2	121,3	214,8	237,2	107,4	83,4	63,2	132,6
■ Lanterna	42,5	20,9	39,4	5,8	42,6	54,6	37,6	97,0	65,3	54,9	93,7	73,1

Figure 73. Winter – Sum of all WWTP’s. Hourly average influent TSS Load based on 7 measurement days, excluding rain event Monday 28-01-2019. This data is used to reconstruct missing data points in the 7-day measurements.

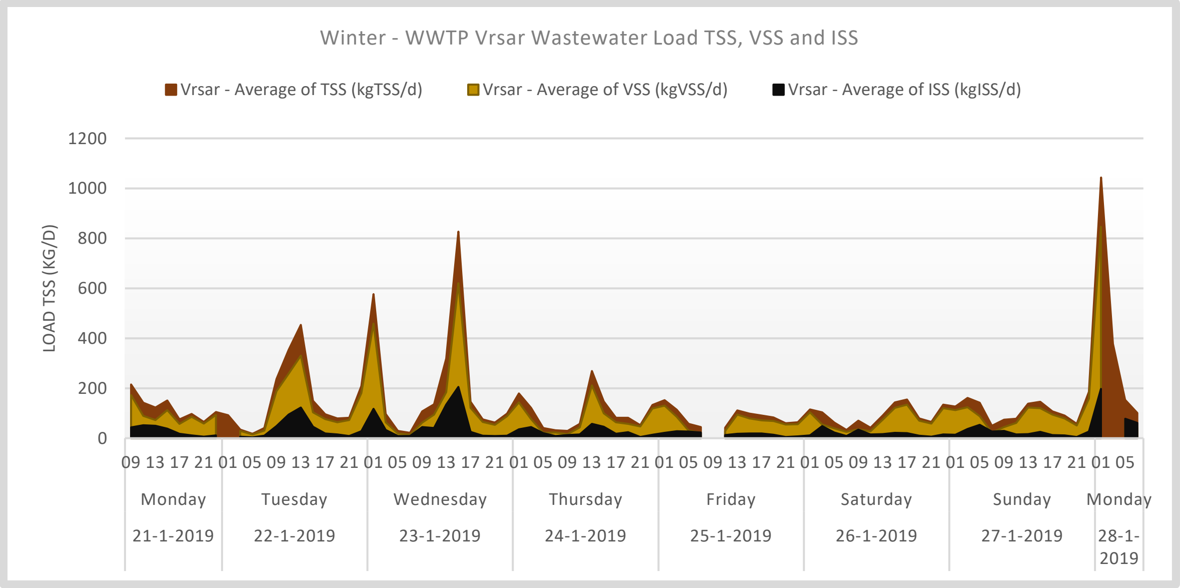
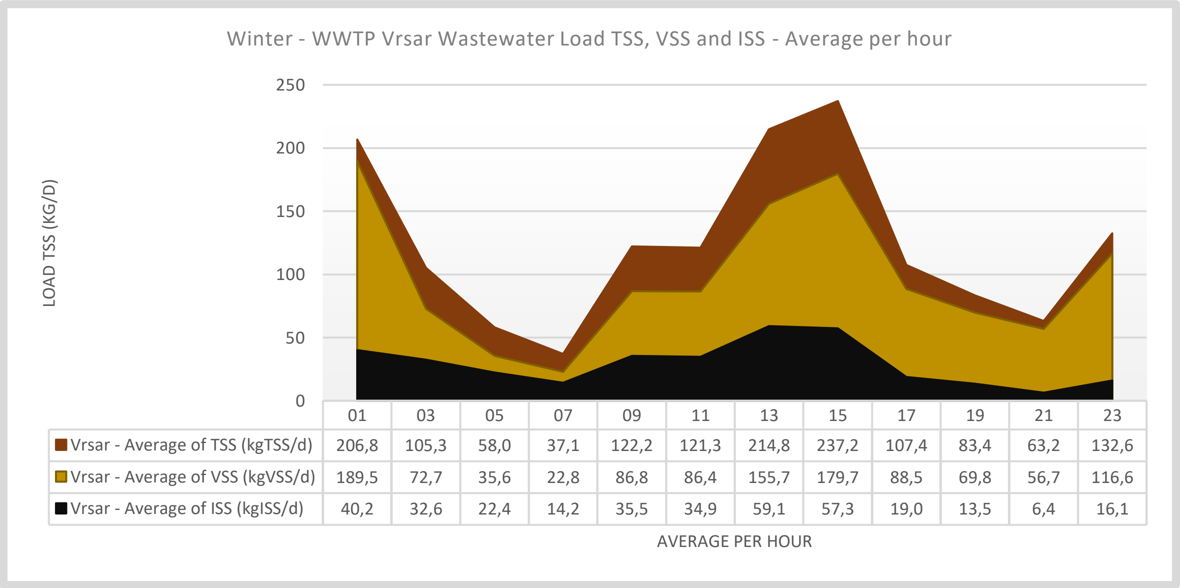


Figure 74. Winter – WWTP Vrsar Influent TSS, VSS and ISS Loads based on 7 measurement days. A rain event occurred Monday 28-01-2019. For the model input missing data points are reconstructed based on the hourly average dry weather load. In practice TSS is difficult to get a homogeneous sample of TSS. TSS is easily biased, especially when automated samplers are used. This often results in high measurement variations.



	01	03	05	07	09	11	13	15	17	19	21	23
■ Vrsar - Average of TSS (kgTSS/d)	206,8	105,3	58,0	37,1	122,2	121,3	214,8	237,2	107,4	83,4	63,2	132,6
■ Vrsar - Average of VSS (kgVSS/d)	189,5	72,7	35,6	22,8	86,8	86,4	155,7	179,7	88,5	69,8	56,7	116,6
■ Vrsar - Average of ISS (kgISS/d)	40,2	32,6	22,4	14,2	35,5	34,9	59,1	57,3	19,0	13,5	6,4	16,1

Figure 75. Winter – WWTP Vrsar hourly average influent loads TSS, VSS and ISS, based on 7 measurement days, excluding the rain event Monday 28-01-2019. This data is used to reconstruct missing data points in 7-day measurement series.

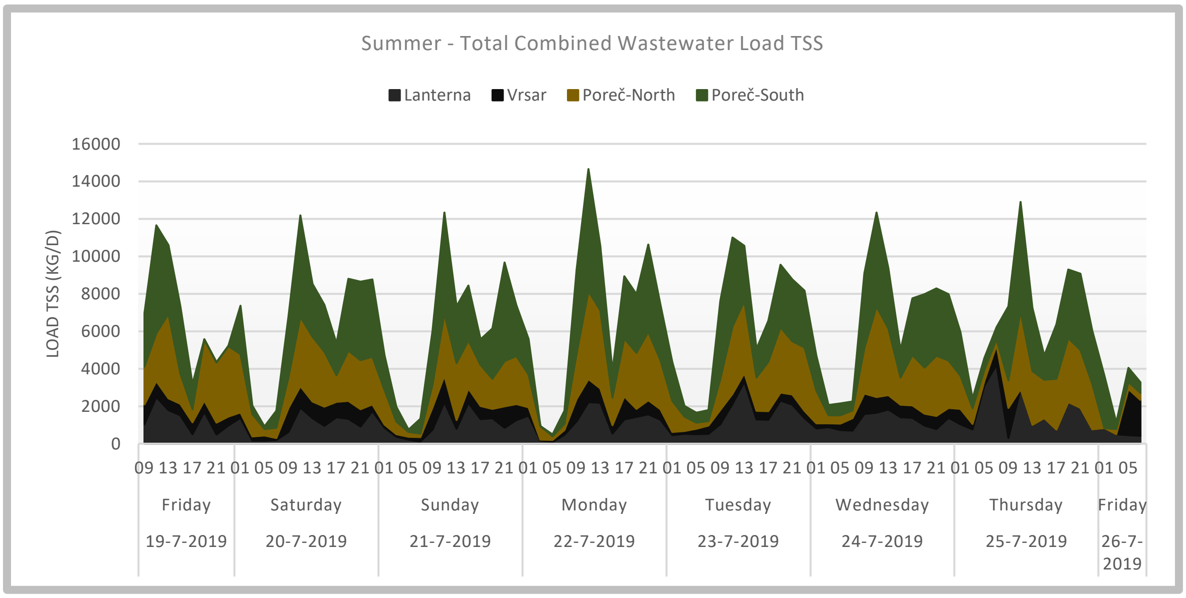
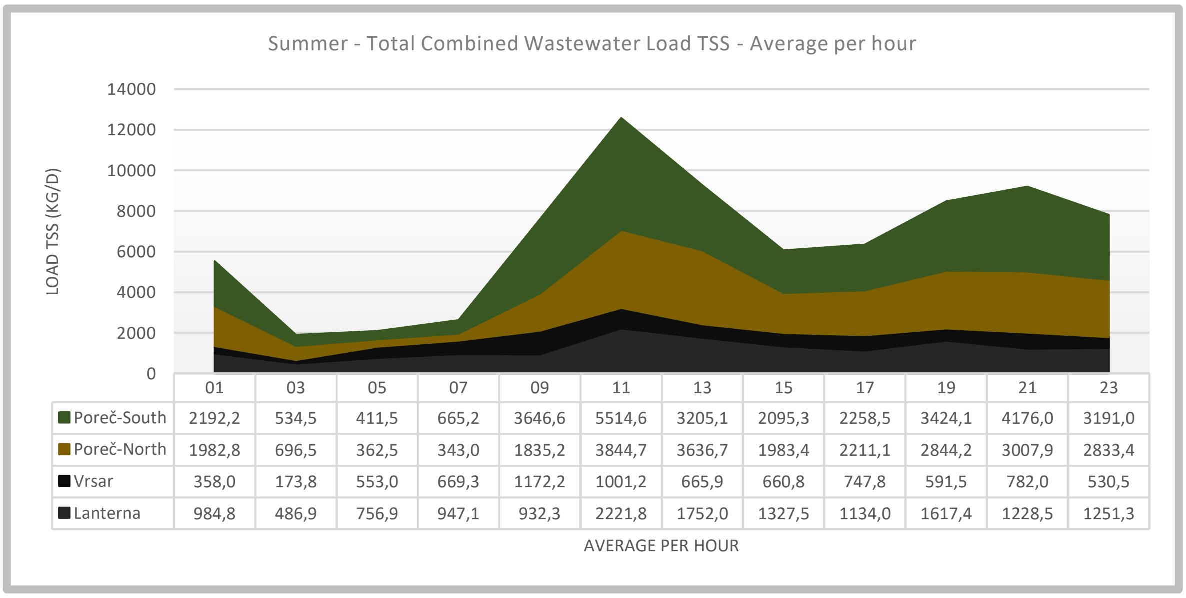


Figure 76. Summer – Sum of all WWTPs. Influent TSS Load measured over 7 days. No rain events occurred during the measurement period. For the model input missing data points are reconstructed based on the hourly average dry weather load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟩 Poreč-South	2192,2	534,5	411,5	665,2	3646,6	5514,6	3205,1	2095,3	2258,5	3424,1	4176,0	3191,0
■ Poreč-North	1982,8	696,5	362,5	343,0	1835,2	3844,7	3636,7	1983,4	2211,1	2844,2	3007,9	2833,4
■ Vrsar	358,0	173,8	553,0	669,3	1172,2	1001,2	665,9	660,8	747,8	591,5	782,0	530,5
■ Lanterna	984,8	486,9	756,9	947,1	932,3	2221,8	1752,0	1327,5	1134,0	1617,4	1228,5	1251,3

Figure 77. Summer – Sum of all WWTP’s. Hourly average influent TSS Loads based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in the 7-day measurements.

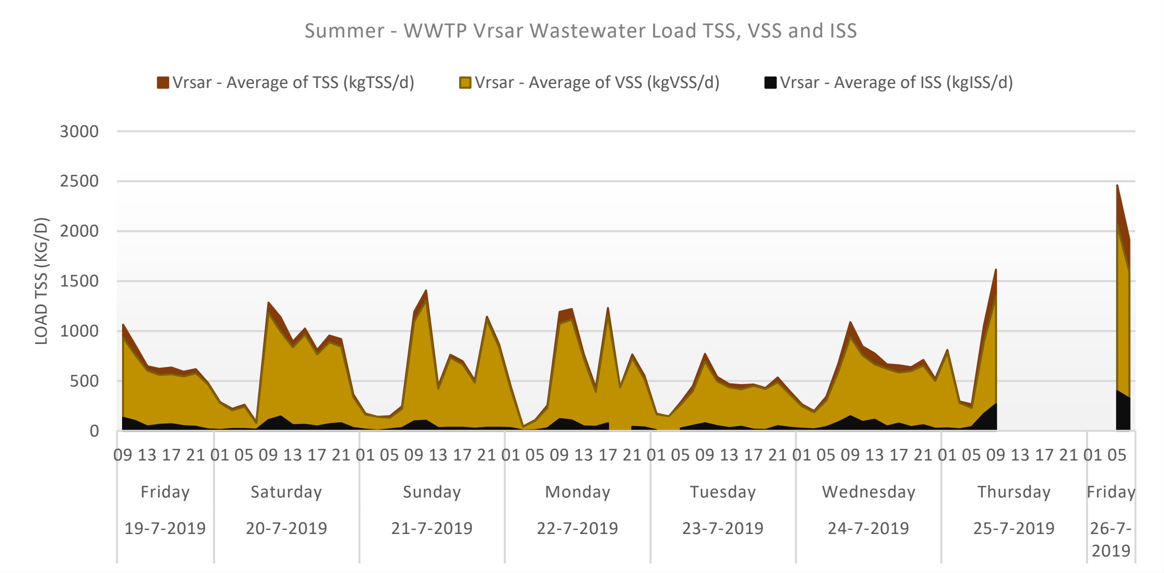
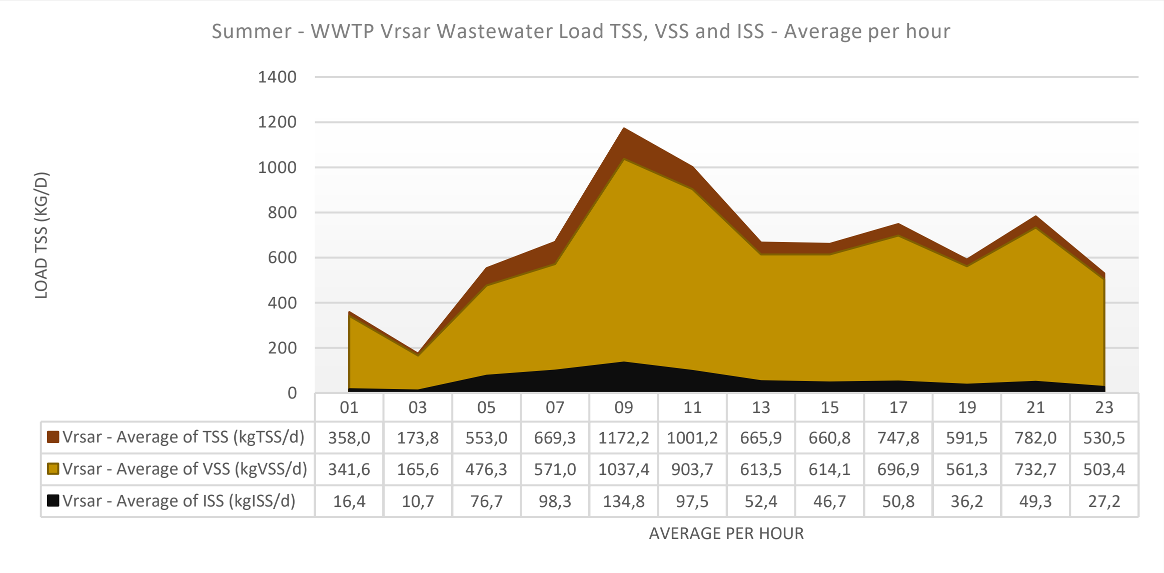


Figure 78. Summer - WWTP Vrsar Wastewater Loads TSS, VSS and ISS. No rain events occurred during the measurement period. For the model input missing data points are reconstructed based on the hourly average load.



	01	03	05	07	09	11	13	15	17	19	21	23
🟫 Vrsar - Average of TSS (kgTSS/d)	358,0	173,8	553,0	669,3	1172,2	1001,2	665,9	660,8	747,8	591,5	782,0	530,5
🟨 Vrsar - Average of VSS (kgVSS/d)	341,6	165,6	476,3	571,0	1037,4	903,7	613,5	614,1	696,9	561,3	732,7	503,4
■ Vrsar - Average of ISS (kgISS/d)	16,4	10,7	76,7	98,3	134,8	97,5	52,4	46,7	50,8	36,2	49,3	27,2

Figure 79. Summer – WWTP Vrsar hourly average influent loads TSS, VSS and ISS, based on 7 measurement days. No rain events occurred during the measurement period. This data is used to reconstruct missing data points in 7-day measurement series.

7 Winter results dynamic modelling

7.1 Winter operation process flow diagram

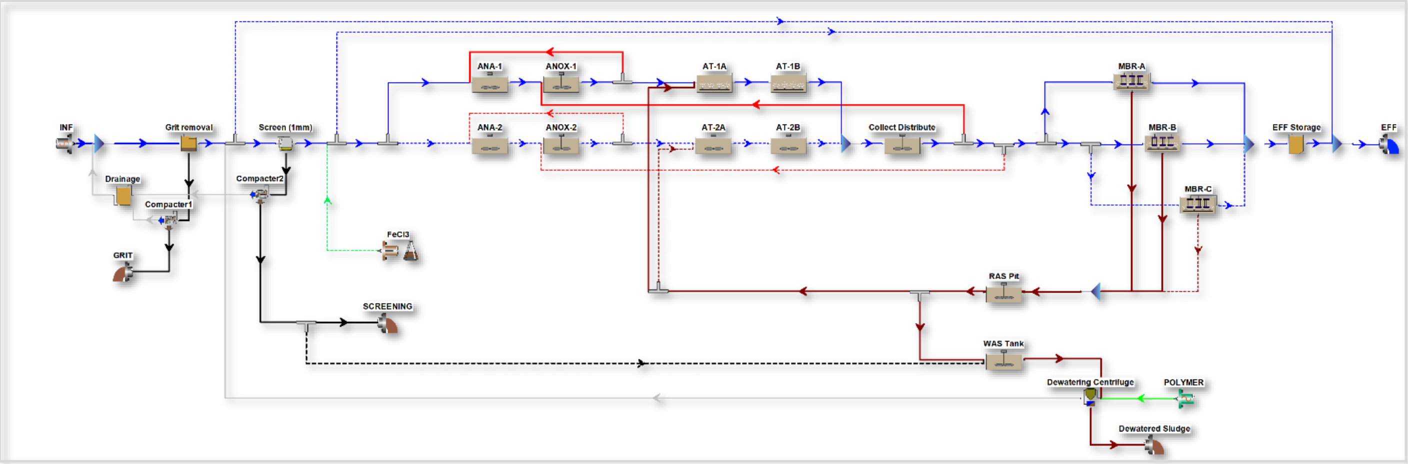


Figure 80. WWTP Vrsar - BioWin model winter operation. One line and one MBR are taken out of operation (dashed lines not operated). Operational adjustments are made to accommodate dynamic modelling. MBR-C is taken out of operation to avoid stripping of alkalinity.

7.2 Performance overview 7-day average

Based on the total dataset including peak loading events and rain events, the average WWTP performance is calculated and presented in the tables below. In average, for the simulated period including rain and peak events and using a simplified process control, the effluent performance and aerobic SRT is in accordance with the design criteria.

Table 5. WWTP Vrsar - Winter 2019 - Dynamic average effluent concentration (mg/L)

WWTP Vrsar - Winter 2019 - Dynamic average effluent concentration (mg/L)			
EFF	Temperature	Concentration	12,0
EFF	COD - Total	Concentration	34,4
EFF	N - Total N	Concentration	5,1
EFF	P - Total P	Concentration	0,7
EFF	Total suspended solids	Concentration	0,5

Table 6. WWTP Vrsar - Winter 2019 - Dynamic average Air flow rate (m3/h)

WWTP Vrsar - Winter 2019 - Dynamic average Air flow rate (m3/h)			
AT-1A	Air flow rate	Flow	180,9
AT-1B	Air flow rate	Flow	71,9
AT-2A	Air flow rate	Flow	0,0
AT-2B	Air flow rate	Flow	0,0
MBR-A	Air flow rate	Flow	110,7
MBR-B	Air flow rate	Flow	110,7
MBR-C	Air flow rate	Flow	0,0

Table 7. WWTP Vrsar - Winter 2019 - Dynamic average Flows (m3/d)

WWTP Vrsar - Winter 2019 - Dynamic average Flows (m3/d)			
ANA-R1	Flow (S)	Flow	1.250,0
ANA-R2	Flow (S)	Flow	0,0
ANOX-R1	Flow (S)	Flow	6.331,7
ANOX-R2	Flow (S)	Flow	0,0
AS Emergency Bypass	Flow (S)	Flow	0,0
Dewatering Centrifuge	Flow (U)	Flow	0,4
Grit removal	Flow (U)	Flow	0,2
MBR-A	Flow (U)	Flow	622,0
MBR-B	Flow (U)	Flow	622,0
MBR-C	Flow (U)	Flow	0,0
Screen (1mm)	Flow (U)	Flow	0,1
Screen Emergency Bypass	Flow (S)	Flow	0,0
WAS Splitter	Flow (S)	Flow	18,5

Table 8. WWTP Vrsar - Winter 2019 - Dynamic average sludge production SRT and HRT

WWTP Vrsar - Winter 2019 - Dynamic average SRT and HRT		
Temperature	12	°C
Average waste sludge production	83,7	kgTSS/d
SRT Total	39,7	d
SRT Aerobic	15,5	d
SRT AT+ANOX	22,7	d
WAS Tank HRT	2,6	hour
ANA HRT to influent	12,8	hour

Table 9. WWTP Vrsar - Winter 2019 - Dynamic average Iron and Polymer (mg/L, kg/d, m3/d)

WWTP Vrsar - Winter 2019 - Dynamic average Iron and Polymer (mg/L & kg/d)			
FeCl3	Flow	Flow	0,0
FeCl3	Total iron (all forms)	Concentration	150.000,0
FeCl3	Total iron (all forms)	Load	0,0
POLYMER	COD - Total	Concentration	18.180,0
POLYMER	COD - Total	Load	1,0
POLYMER	Flow	Flow	0,1

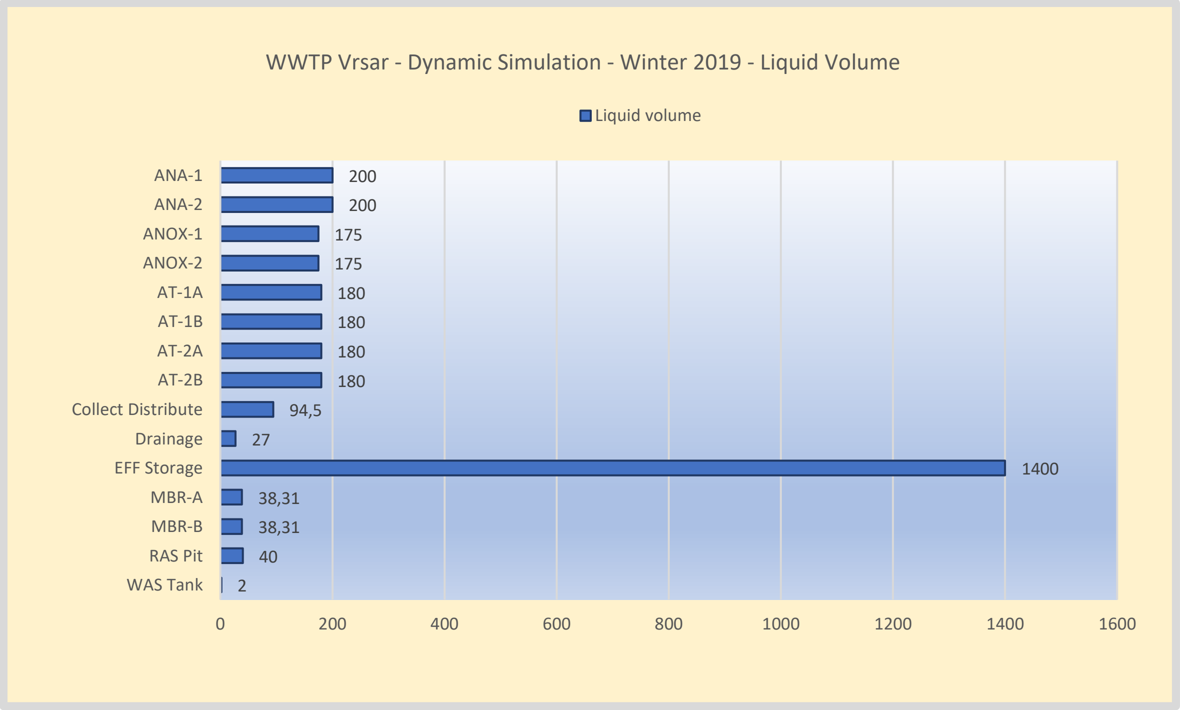


Figure 81. WWTP Vrsar – Volume distribution of modelled reactor elements. The actual WAS tank is 150 m3 however the sludge volume is modelled based on an HRT less than 2,5 hours to avoid P-release. The WAS tank is not suitable for sludge storage.

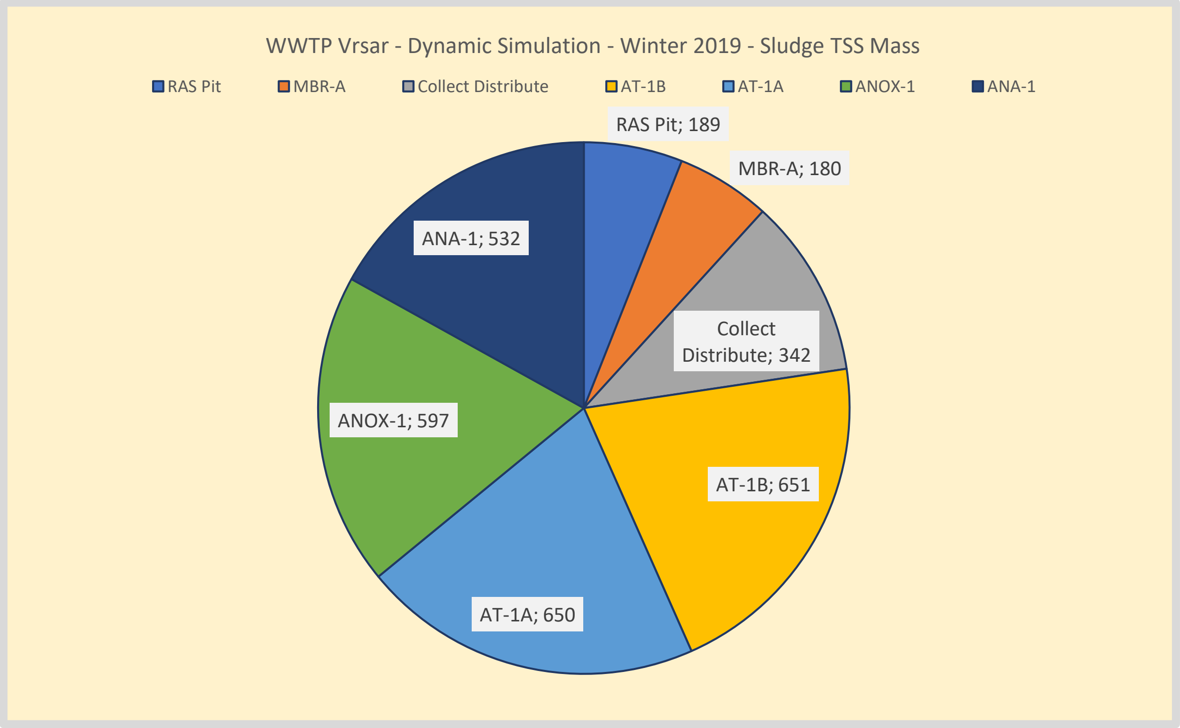
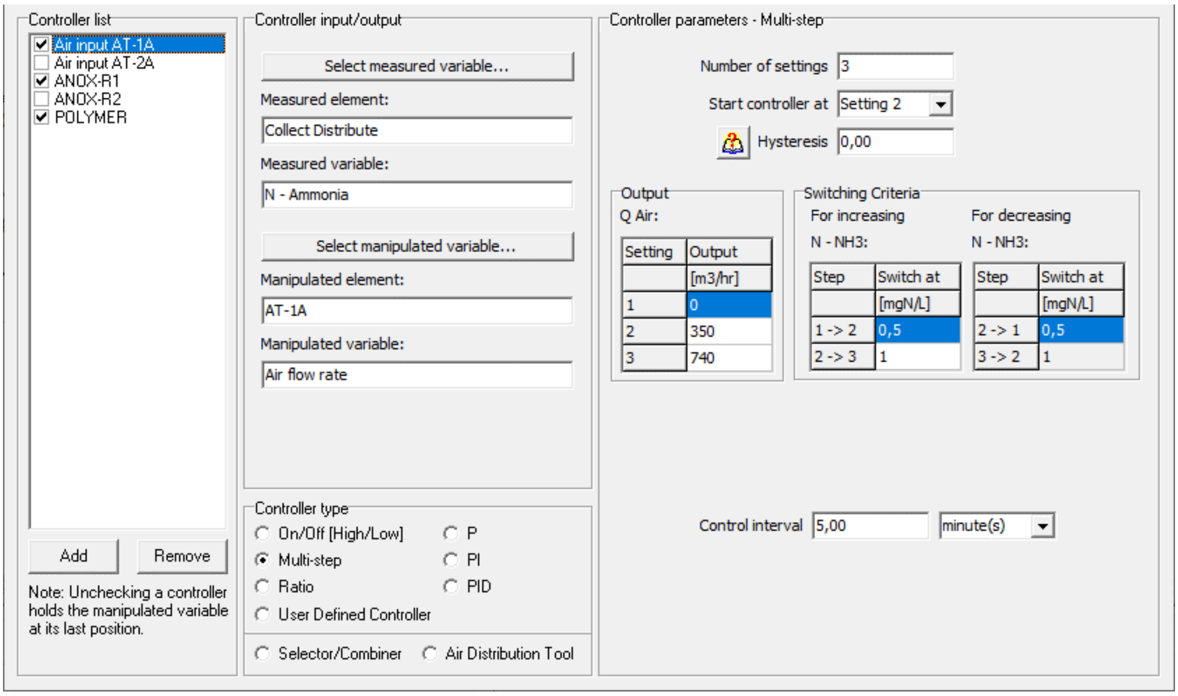


Figure 82. Winter – WWTP Vrsar sludge mass distribution (kgTSS) in the reactor tanks. Based on these data and the average sludge production, the SRT of the WWTP is calculated. Mass of idle tanks is not included.

7.3 Winter process controllers.



Controller list

☑ Air input AT-1A
☐ Air input AT-2A
☑ ANOX-R1
☐ ANOX-R2
☑ POLYMER

Note: Unchecking a controller holds the manipulated variable at its last position.

Controller input/output

Measured element: Collect Distribute

Measured variable: N - Ammonia

Manipulated element: AT-1A

Manipulated variable: Air flow rate

Controller type

○ On/Off [High/Low]
○ P
● Multi-step
○ PI
○ Ratio
○ PID
○ User Defined Controller
○ Selector/Combiner
○ Air Distribution Tool

Controller parameters - Multi-step

Number of settings 3

Start controller at Setting 2

Hysteresis 0,00

Output

Q Air:

Setting	Output
	[m3/hr]
1	0
2	350
3	740

Switching Criteria

For increasing N - NH3:

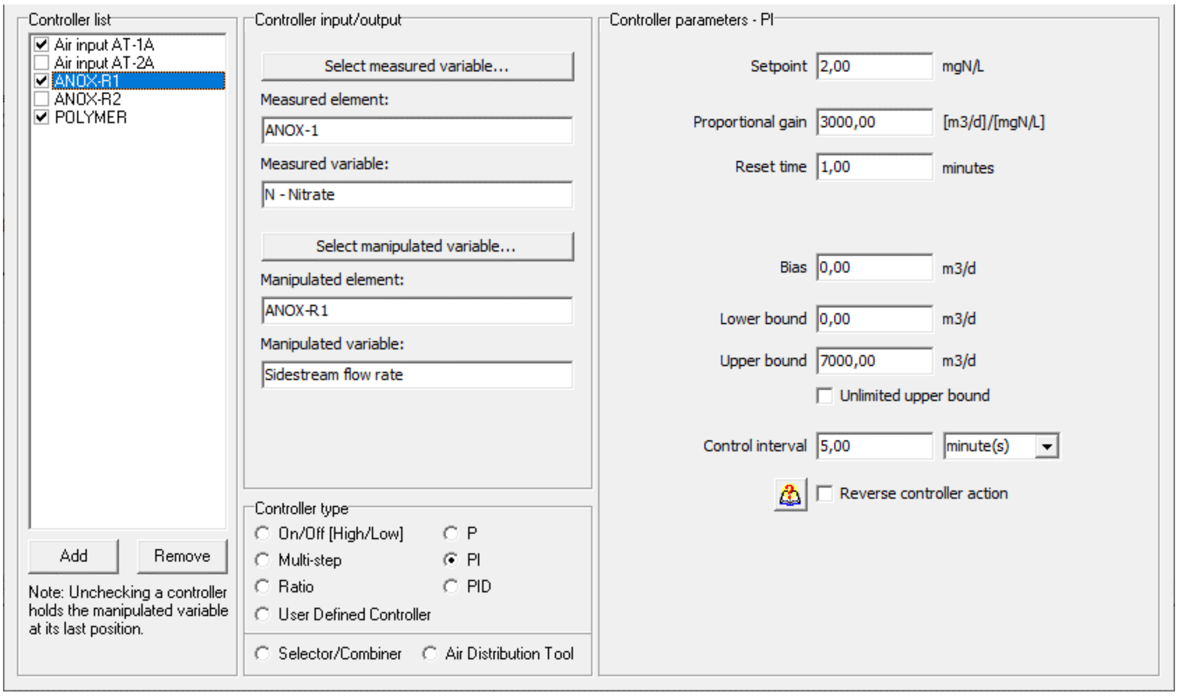
Step	Switch at
	[mgN/L]
1 -> 2	0,5
2 -> 3	1

For decreasing N - NH3:

Step	Switch at
	[mgN/L]
2 -> 1	0,5
3 -> 2	1

Control interval 5,00 minute(s)

Figure 83. Winter – WWTP Vrsar BioWin controller toolbox used for controlling the air input of AT-A. The measured variable is NH4 in the collect distribute tank. The manipulated variable the air flow in AT-A. There are 3 settings for the air flow depending on the NH4 concentration.



Controller list

☑ Air input AT-1A
☐ Air input AT-2A
☑ ANOX-R1
☐ ANOX-R2
☑ POLYMER

Note: Unchecking a controller holds the manipulated variable at its last position.

Controller input/output

Measured element: ANOX-1

Measured variable: N - Nitrate

Manipulated element: ANOX-R1

Manipulated variable: Sidestream flow rate

Controller type

○ On/Off [High/Low]
○ P
○ Multi-step
● PI
○ Ratio
○ PID
○ User Defined Controller
○ Selector/Combiner
○ Air Distribution Tool

Controller parameters - PI

Setpoint 2,00 mgN/L

Proportional gain 3000,00 [m3/d]/[mgN/L]

Reset time 1,00 minutes

Bias 0,00 m3/d

Lower bound 0,00 m3/d

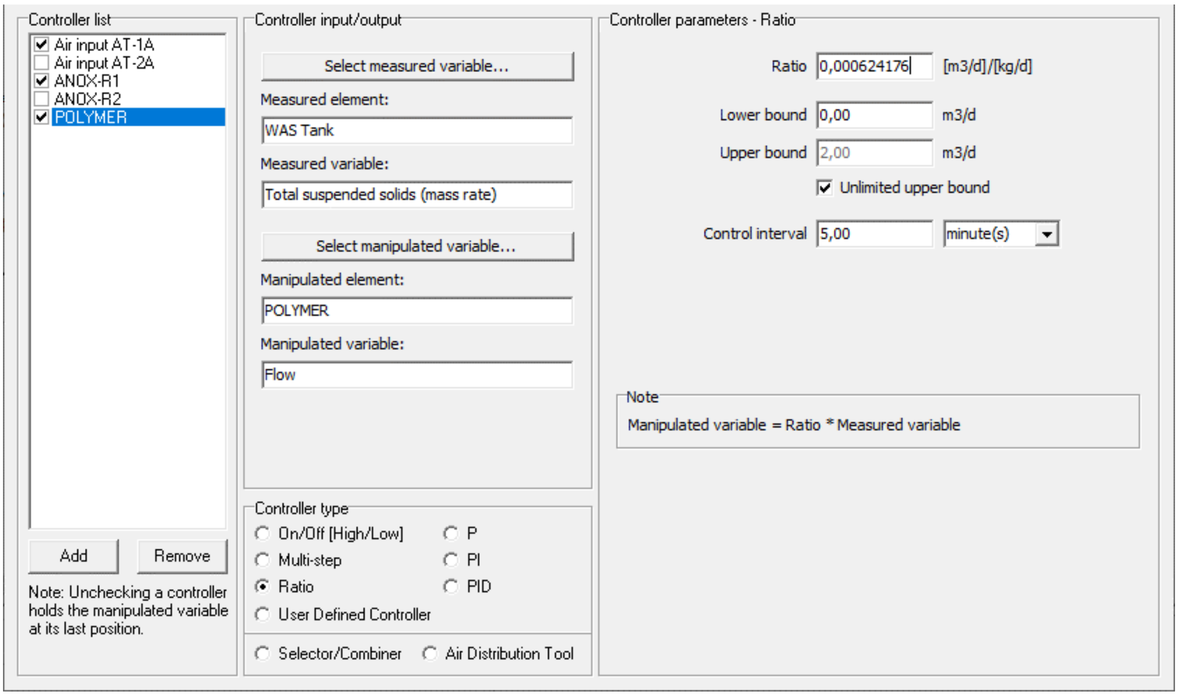
Upper bound 7000,00 m3/d

☐ Unlimited upper bound

Control interval 5,00 minute(s)

☐ Reverse controller action

Figure 84. Winter – WWTP Vrsar BioWin controller toolbox used for controlling the anoxic recycle ANOX-R. Indicated are the measured variable being NO3 in the anoxic tank and manipulated variable the recycle flow ANOX-R. The PI controller has an upper bound of 7.000 m3/d according to the maximum installed pump capacity per lane.


Controller list

- ☑ Air input AT-1A
- ☐ Air input AT-2A
- ☑ ANOX-R1
- ☐ ANOX-R2
- ☑ POLYMER

Note: Unchecking a controller holds the manipulated variable at its last position.

Controller input/output

Measured element: WAS Tank

Measured variable: Total suspended solids (mass rate)

Manipulated element: POLYMER

Manipulated variable: Flow

Controller type

○ On/Off [High/Low] ○ P
○ Multi-step ○ PI
● Ratio ○ PID
○ User Defined Controller
○ Selector/Combiner ○ Air Distribution Tool

Controller parameters - Ratio

Ratio 0,000624176 [m3/d]/[kg/d]
Lower bound 0,00 m3/d
Upper bound 2,00 m3/d
☑ Unlimited upper bound
Control interval 5,00 minute(s)

Note
Manipulated variable = Ratio * Measured variable

Figure 85. Winter – WWTP Vrsar BioWin controller toolbox used for controlling the polymer dosage of the dewatering. Indicated are the measured variable being the TSS load entering the dewatering and manipulated variable the PE flow. The applied control ratio is 8 kg PE per 1000 kg TSS based on dry weight. PE is assumed to be particulate substrate with a COD/VSS ratio of 1,42.

7.4 Influent modelling results

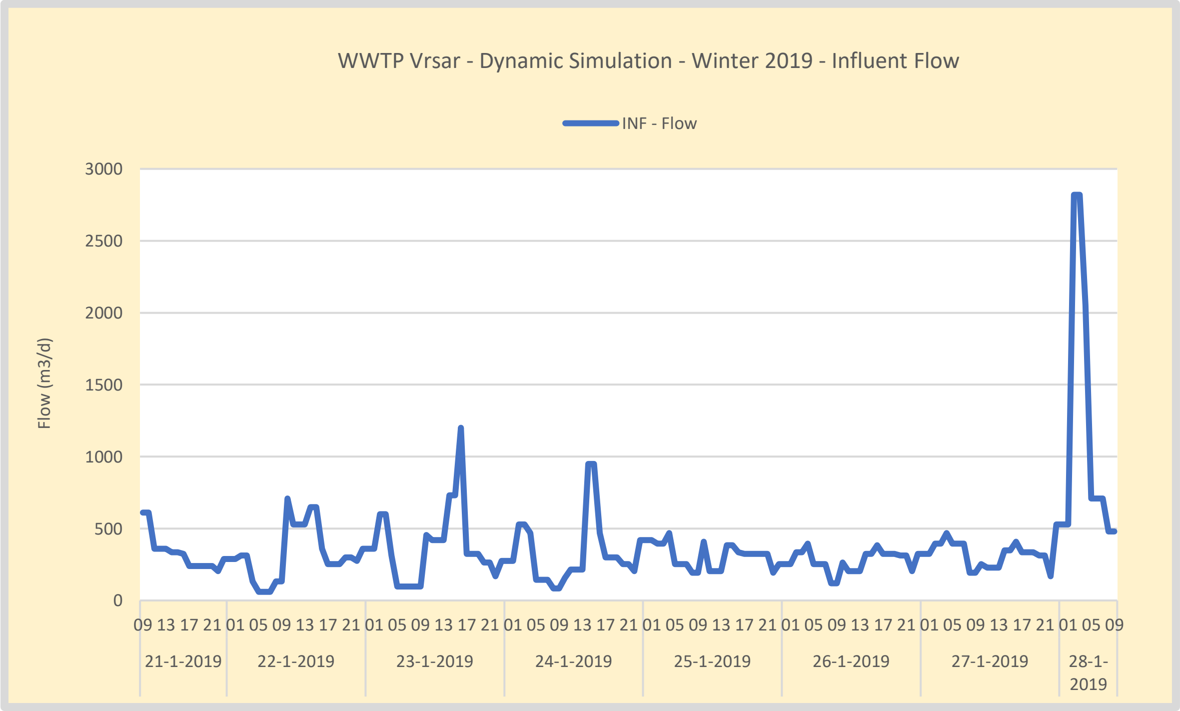


Figure 86. Winter – WWTP Vrsar Influent flow. 28-01-2019 a major rain event occurred.

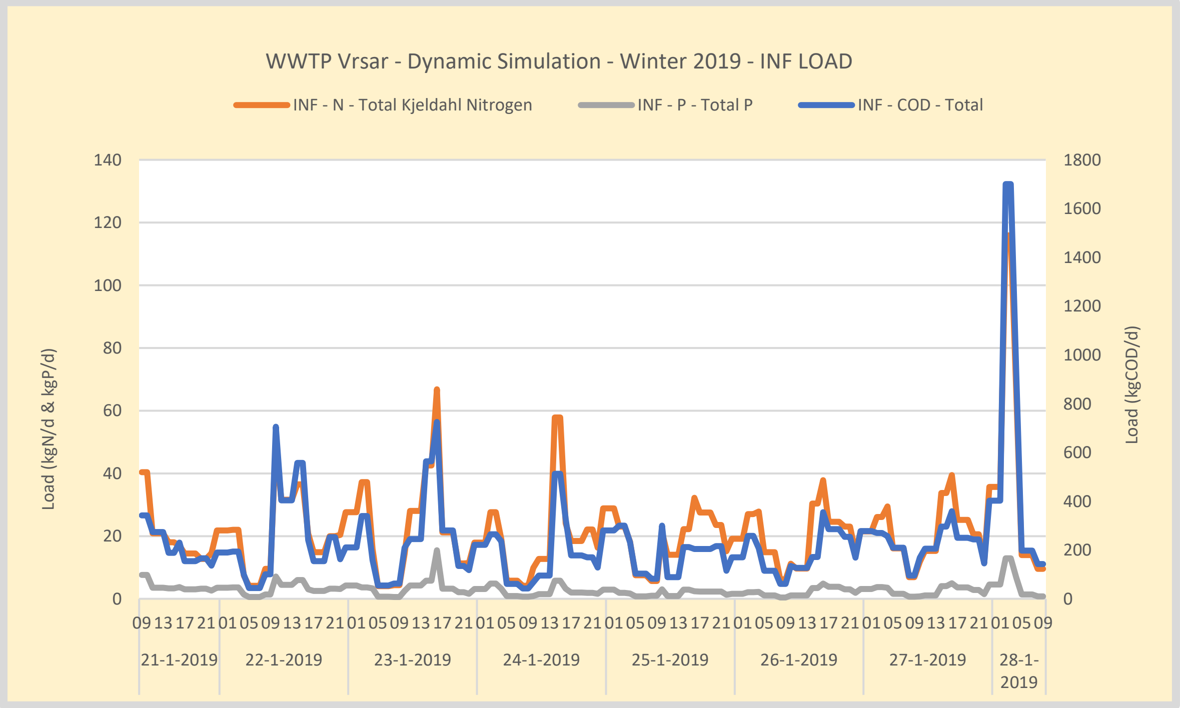


Figure 87. Winter – WWTP Vrsar Influent loads COD, TKN and TP. 28-01-2019 a major rain event occurred. Considerable influent peak loading events cause daily fluctuations in the effluent nitrate concentration.

7.5 Process and recycle flows modelling results

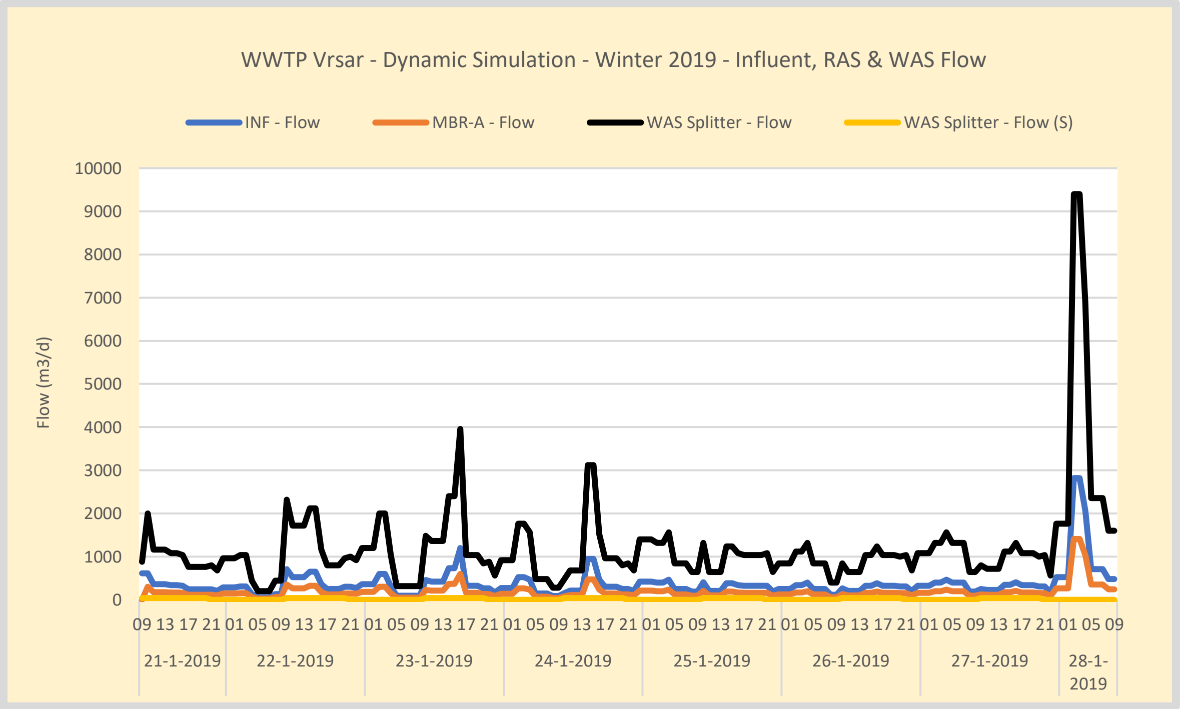


Figure 88. Winter – WWTP Vrsar flow rate settings and control. The MLSS sludge return flow is controlled proportional to the influent. This results in a more stable TSS concentration in the reactors. The WAS flow is operated 10 hours a day on a constant flow to the dewatering.

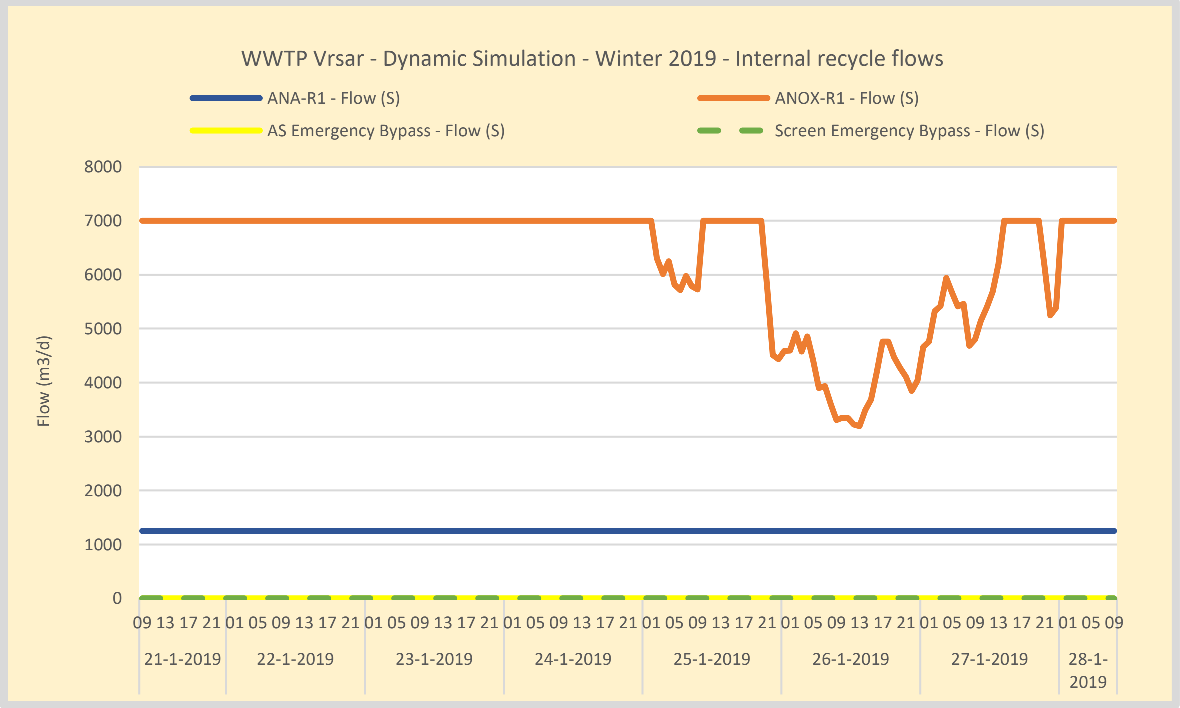


Figure 89. Winter – WWTP Vrsar flow rate settings and control. The bypasses are not used. The upper bound of the anoxic recycle is according to the design. The anoxic recycle is controlled based on nitrate in the anoxic tank. The flow is reduced when Nitrate becomes higher than 2 mgNO3/L. This happens the last part of the week.

7.6 Waterline operation modelling results

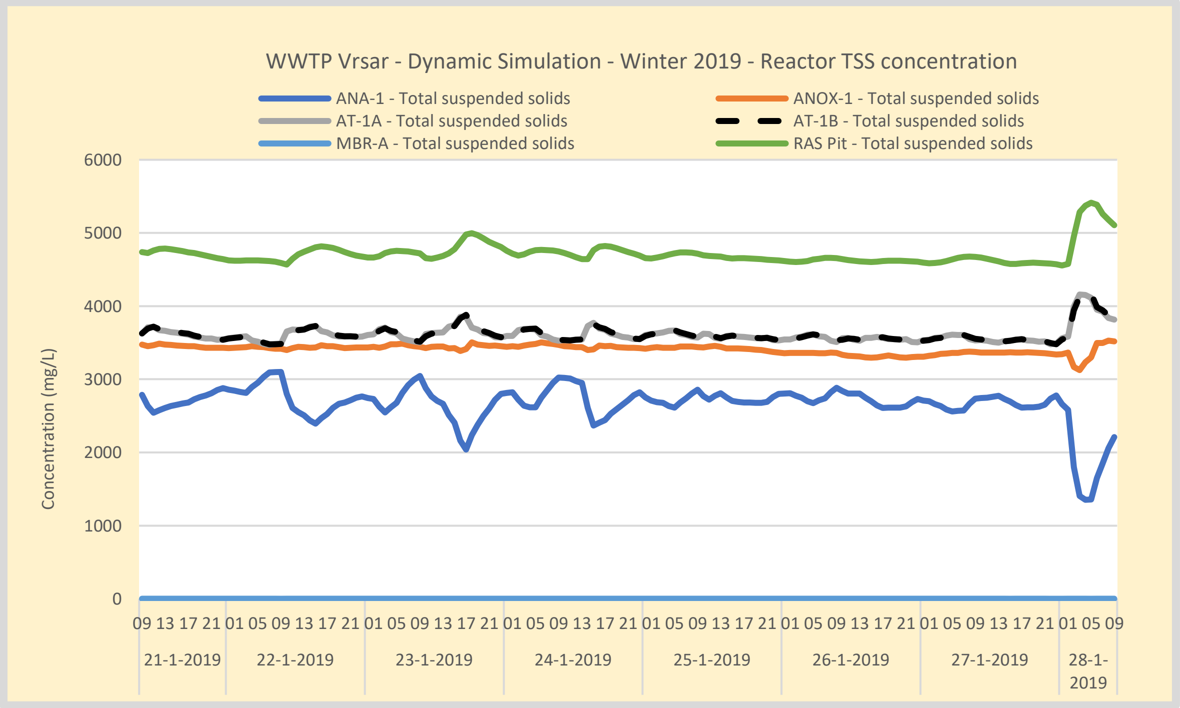


Figure 90. Winter – WWTP Vrsar TSS profile in the waterline. TSS in the MBR is controlled on approximately 5 gTSS/L by adjusting the WAS flow and SRT. In the winter, the reactor volume relative to the influent loading is very high. This results in low sludge production and a too long SRT. The process is therefore operated with a lower TSS concentration during the winter.

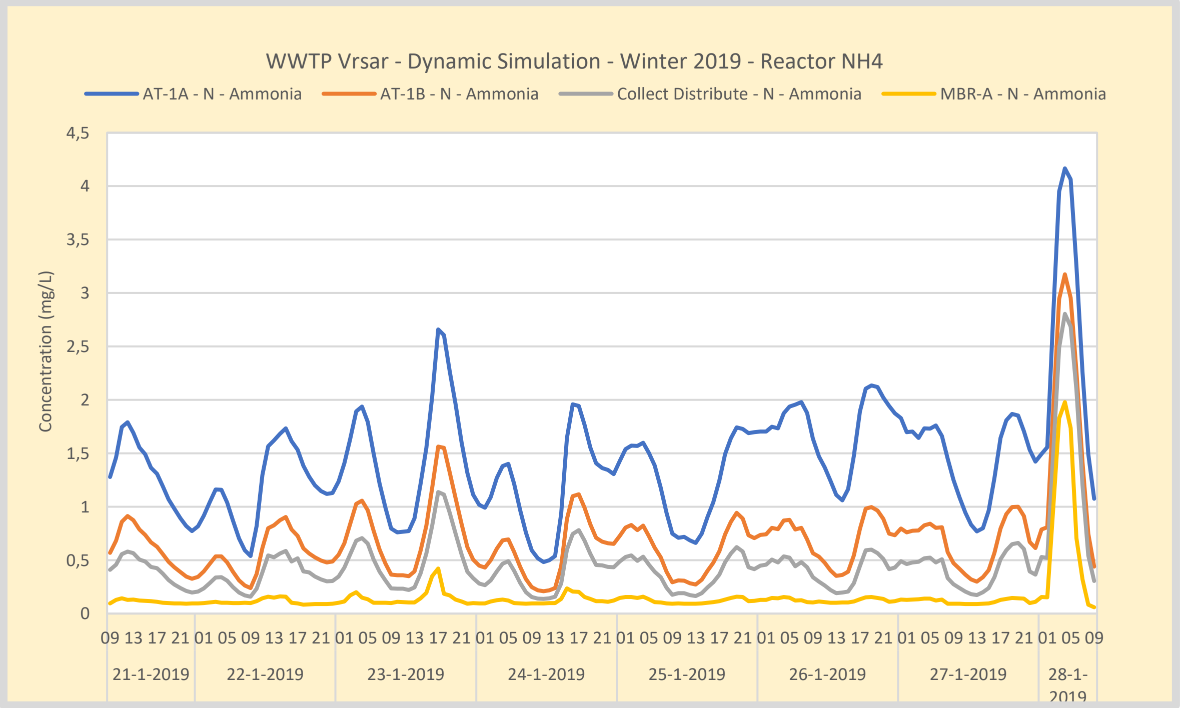


Figure 91. Winter – WWTP Vrsar ammonium profile in the waterline. The air input of AT-A is controlled based on NH4 measured in the collect distribute tank using a 3-step controller. Above 1,0 mgNH4/L the air input goes to its maximum value. Below 0,5 air shuts off. AT-B is DO controlled on 2,0 mgO2/L.

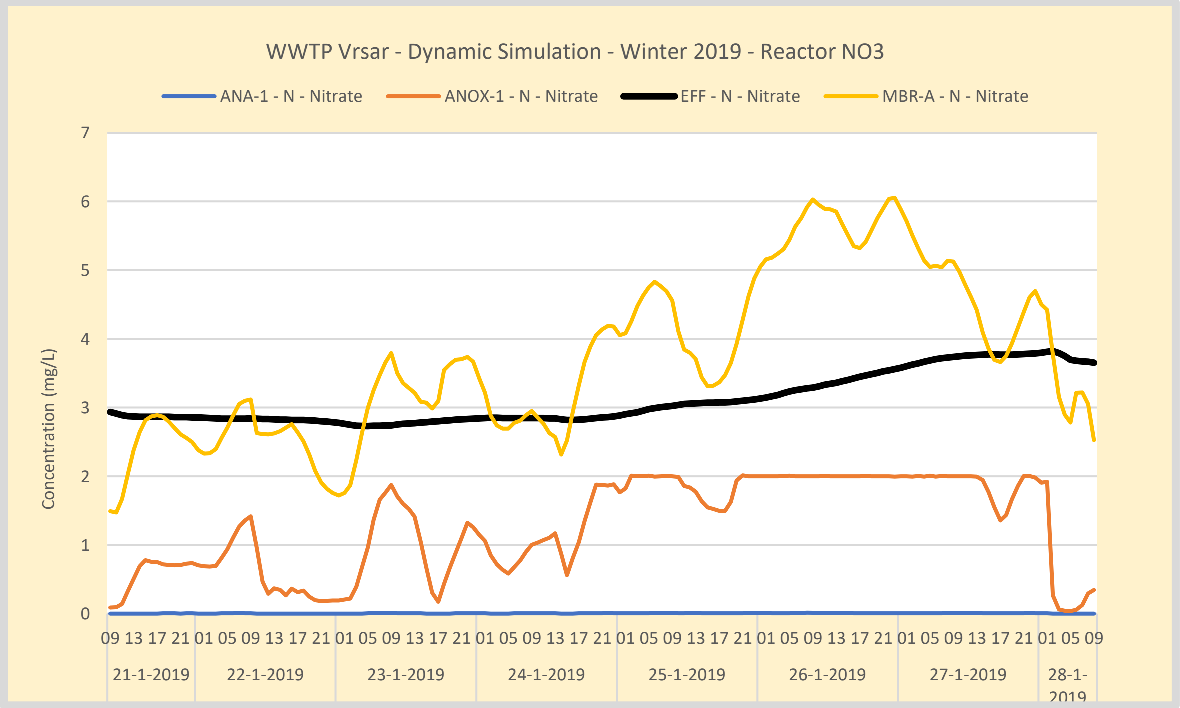


Figure 92. Winter – WWTP Vrsar nitrate in the anoxic tank. The anoxic recycle rate is controlled on a nitrate setpoint of 2 mgNO3/L in the anoxic tank.

7.7 Waterline concentration profiles modelling results

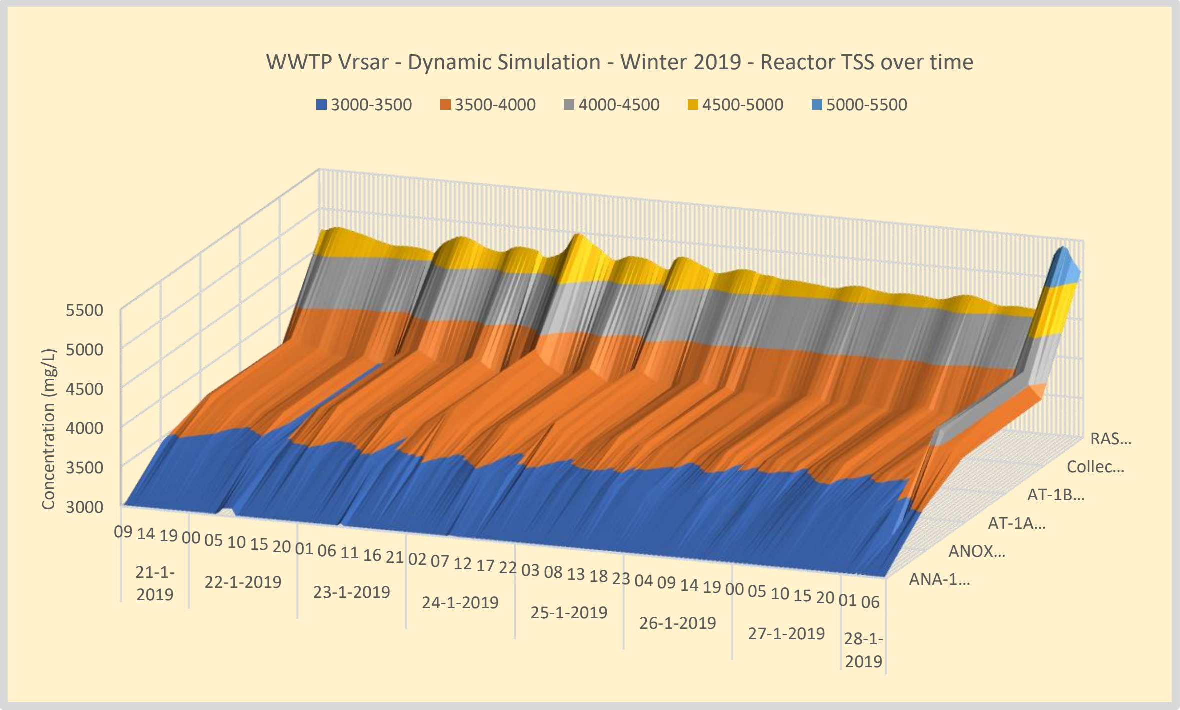


Figure 93. Winter – WWTP Vrsar TSS concentration profile over the waterline.

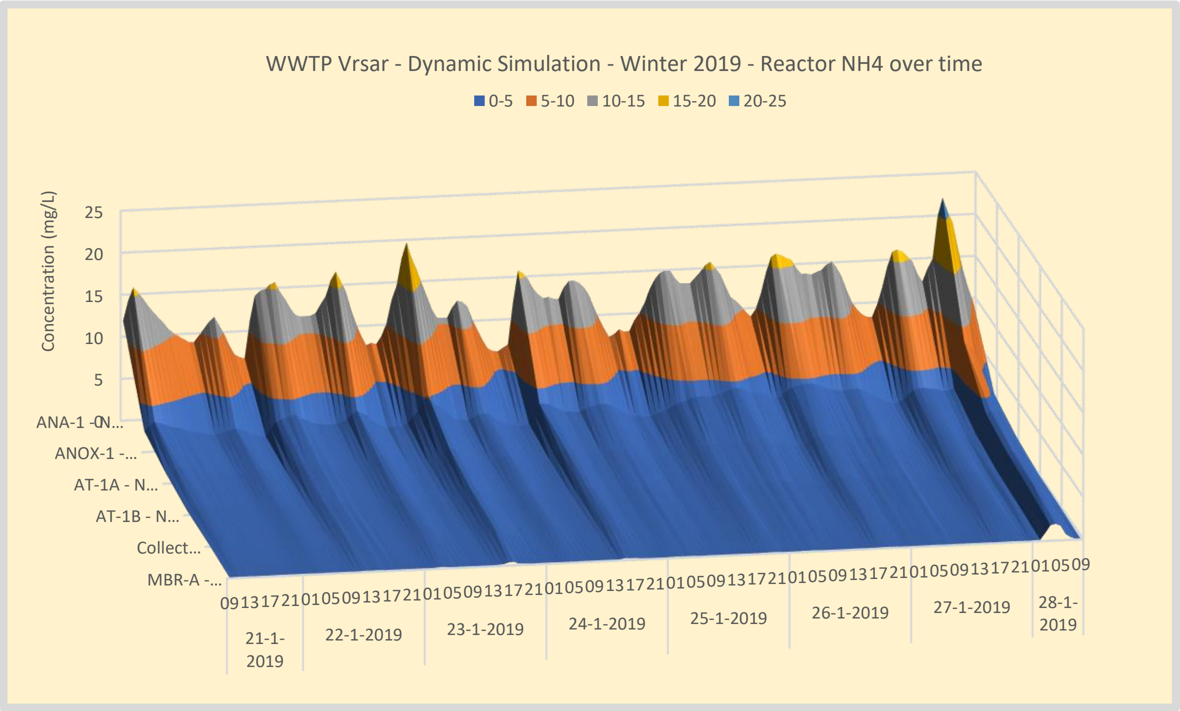


Figure 94. Winter – WWTP Vrsar NH4 concentration profile over the waterline.

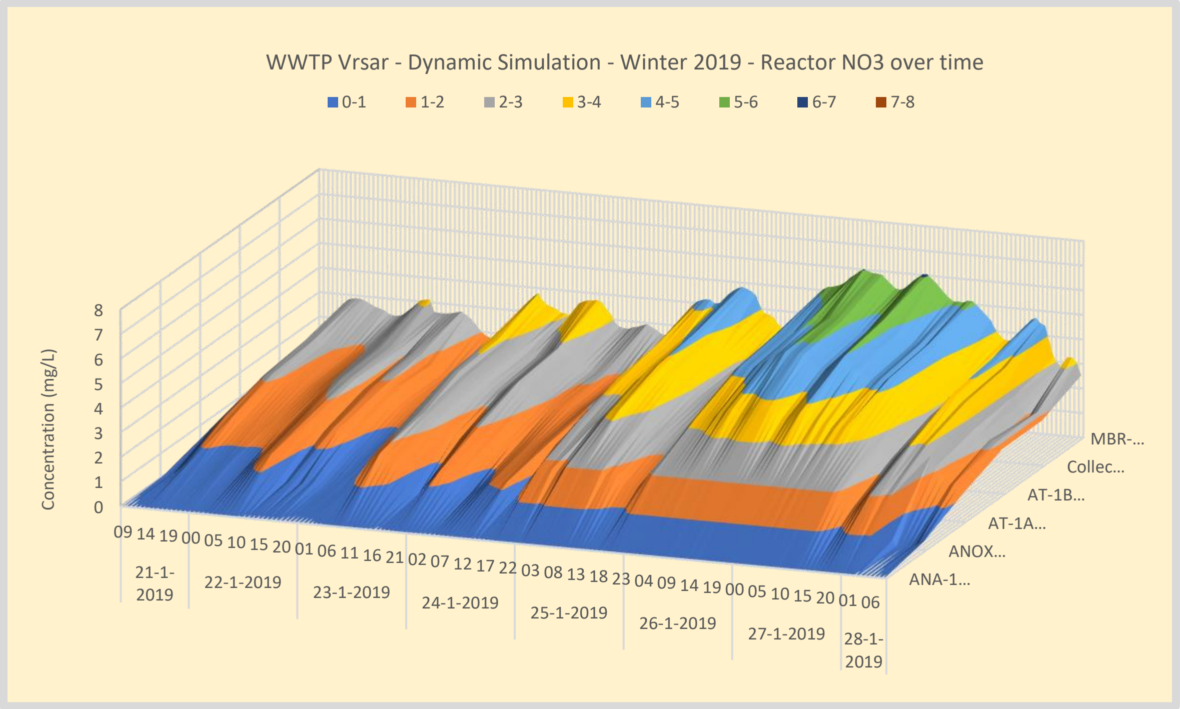


Figure 95. Winter – WWTP Vrsar NO3 concentration profile over the waterline.

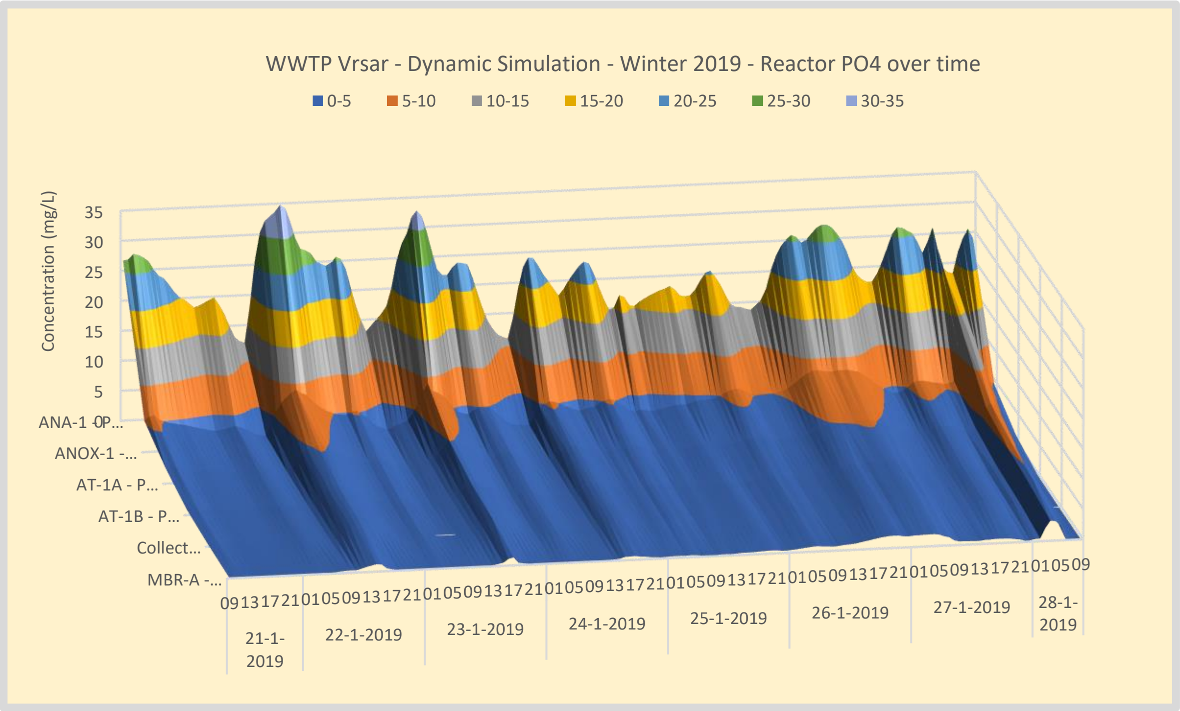


Figure 96. Winter – WWTP Vrsar PO4 concentration profile over the waterline.

7.8 Aeration and DO concentration modelling results

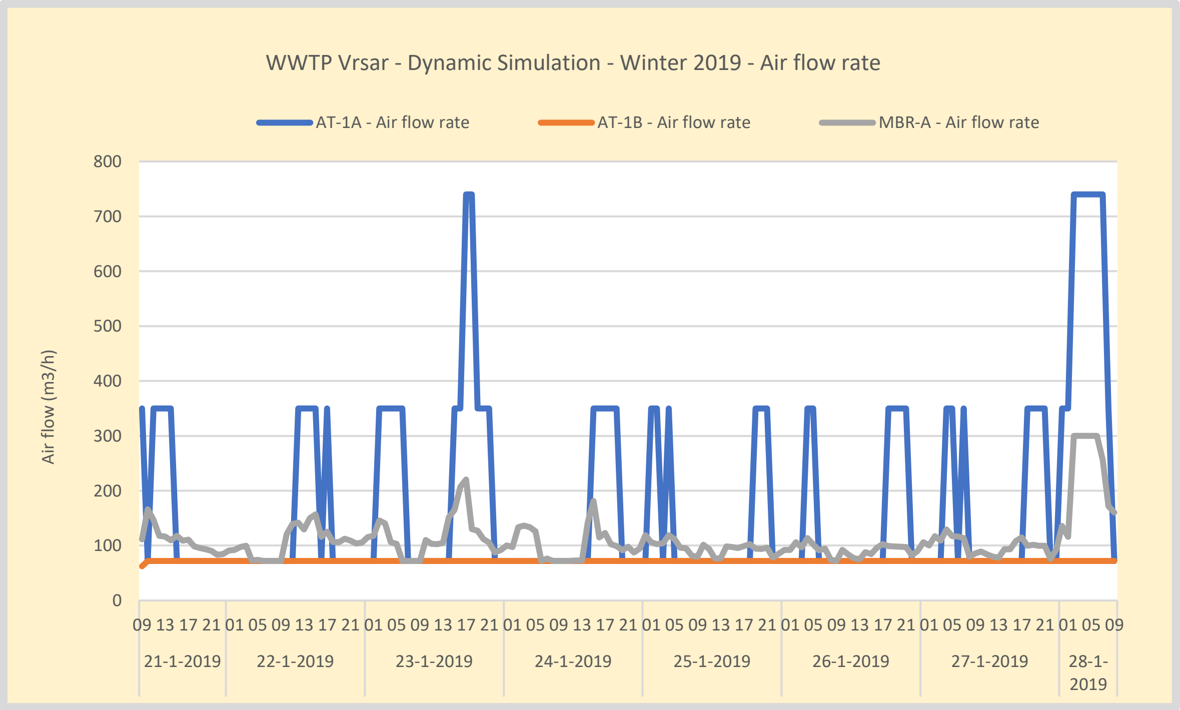


Figure 97. Winter – WWTP Vrsar air input in the different aerated reactors. AT-A is step controlled on NH4, AT-B is setpoint controlled on the DO, the MBR is fully aerated according to the design value. AT-B is setpoint controlled on the DO, the MBR is fully aerated according to the design value. Recycled DO rich water is sufficient to reach the setpoint in AT-B. The controller falls back on a minimum operational value.

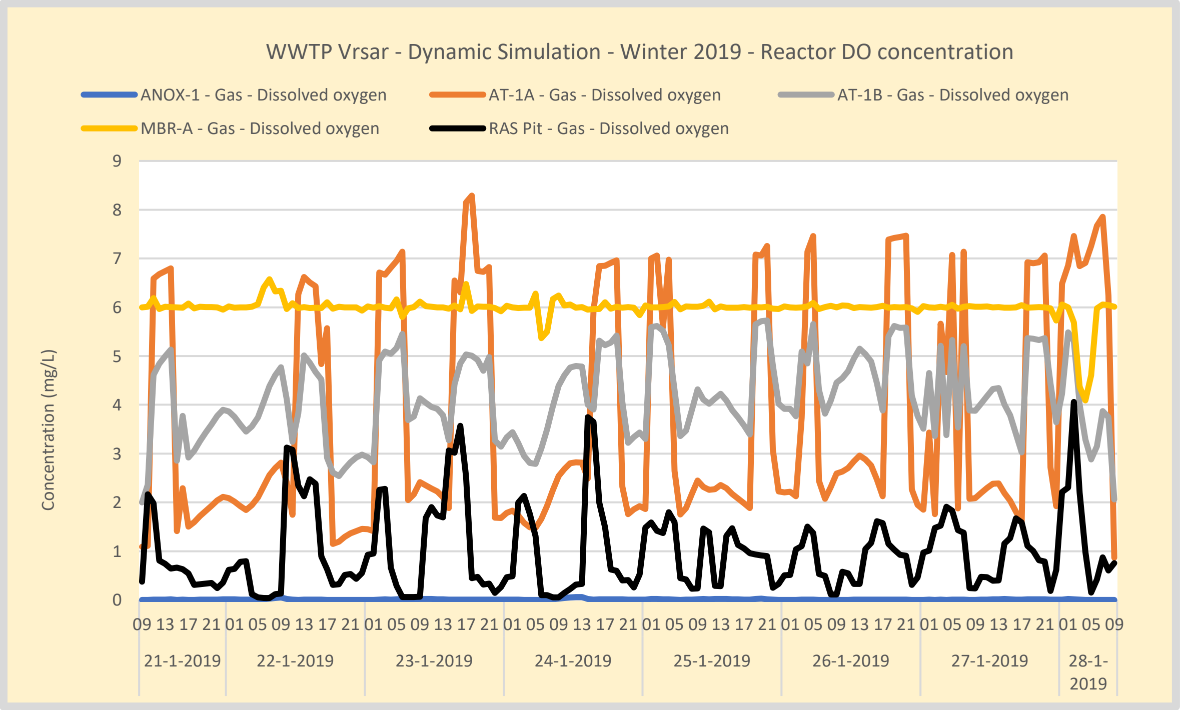


Figure 98. Winter – WWTP Vrsar DO concentration gradients. DO is controlled in the AT. In the MBR the DO is the result of the designed air input. Oxygen is recycled over the reactors causing accumulation of DO in the AT during periods of low influent loading.

7.9 pH and alkalinity profiles modelling results

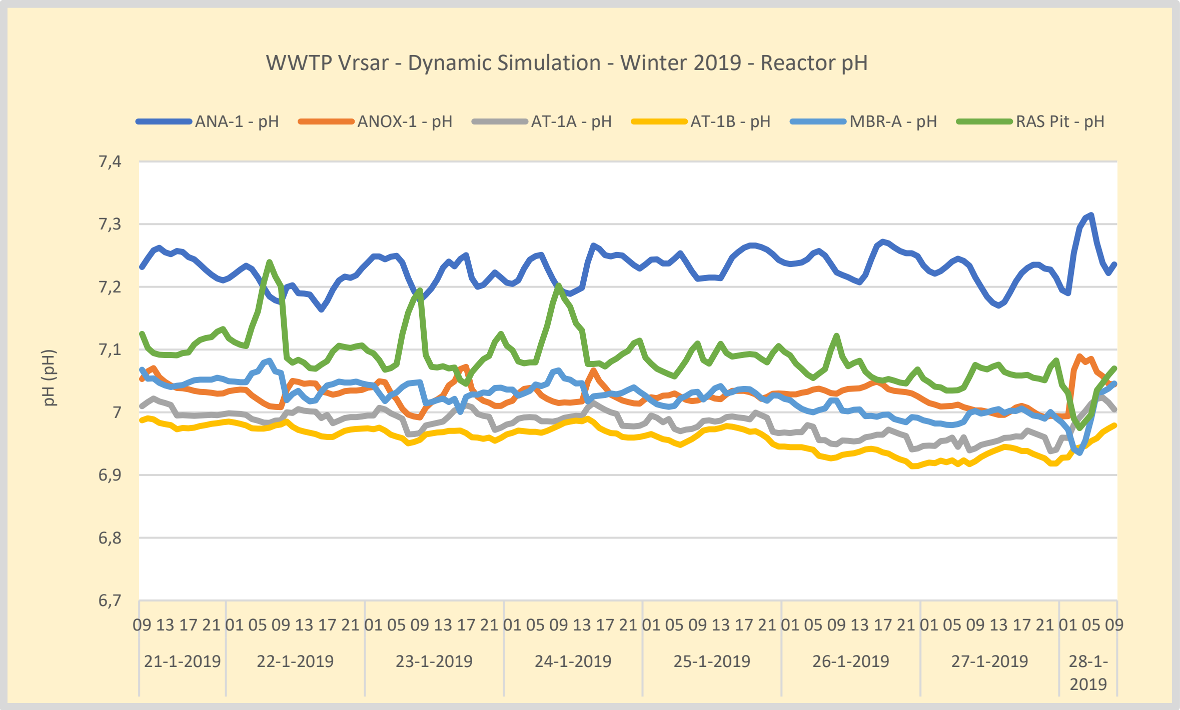


Figure 99. Winter – WWTP Vrsar pH profile over the activated sludge reactors. Influent pH is measured continuously and is not limiting.

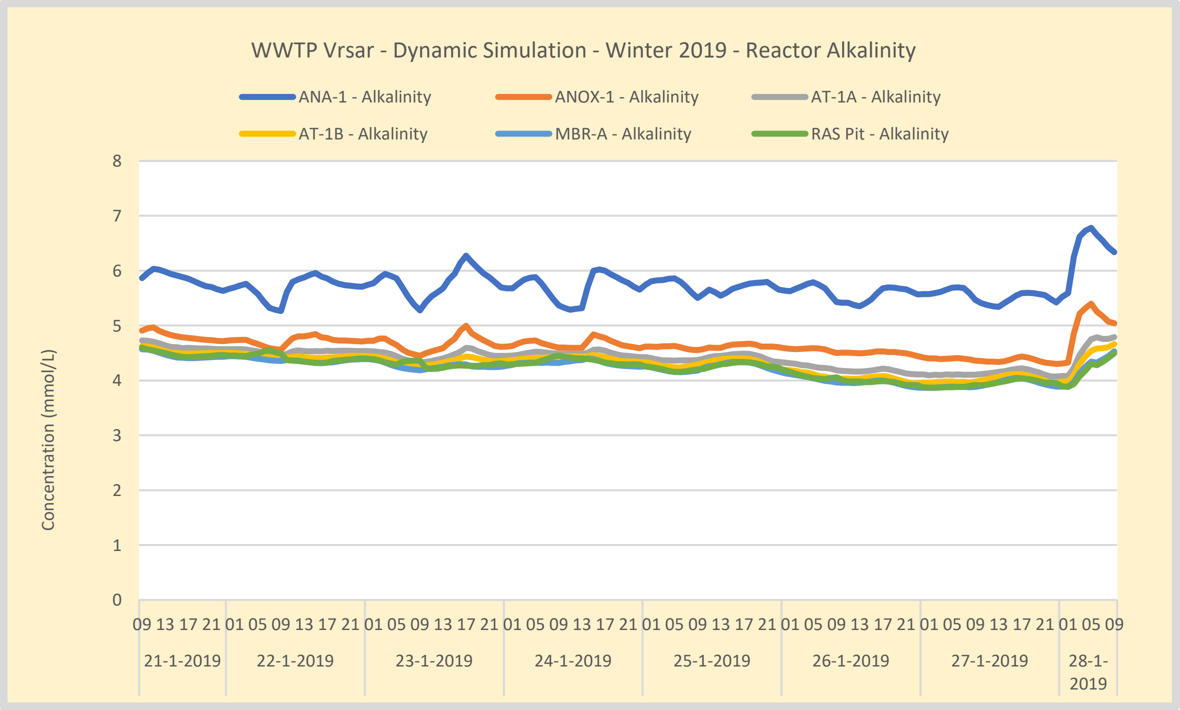


Figure 100. Winter – WWTP Vrsar alkalinity profile over the activated sludge reactors. Influent alkalinity is estimated from local drinking water quality measurements at 7,46 mmol/L. Alkalinity is not limiting.

7.10 Chemical load and flow modelling results

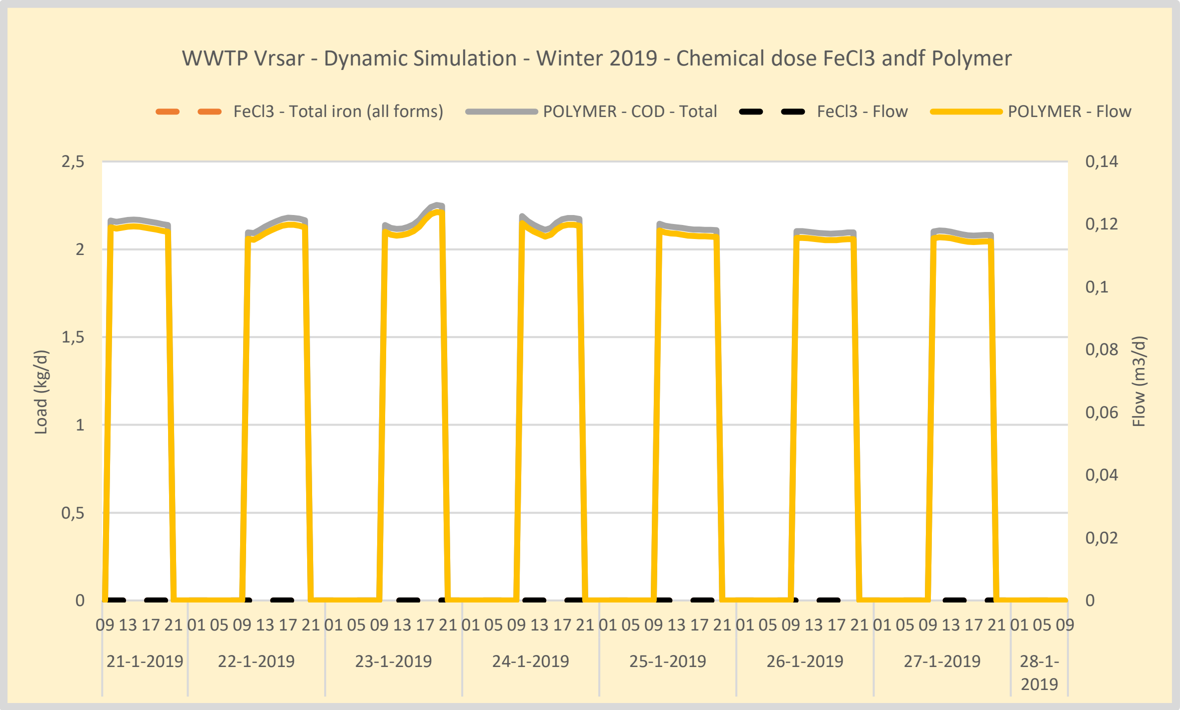


Figure 101. Winter – WWTP Vrsar load and flow of Iron and PE. No Iron dosage is required for P-removal. PE is assumed particulate biodegradable COD with a COD/VSS ratio of 1,42 gCOD/gTSS and dosed proportional to the WAS load based on 8 kg PE (dry weight) dosed per 1000 kg WAS (dry weight) flowing in the dewatering.

7.11 Sludge line operation modelling results

In the figures below the dynamic operation of the sludge line including dynamic WAS control is presented under winter conditions. The last day included a major rain event.

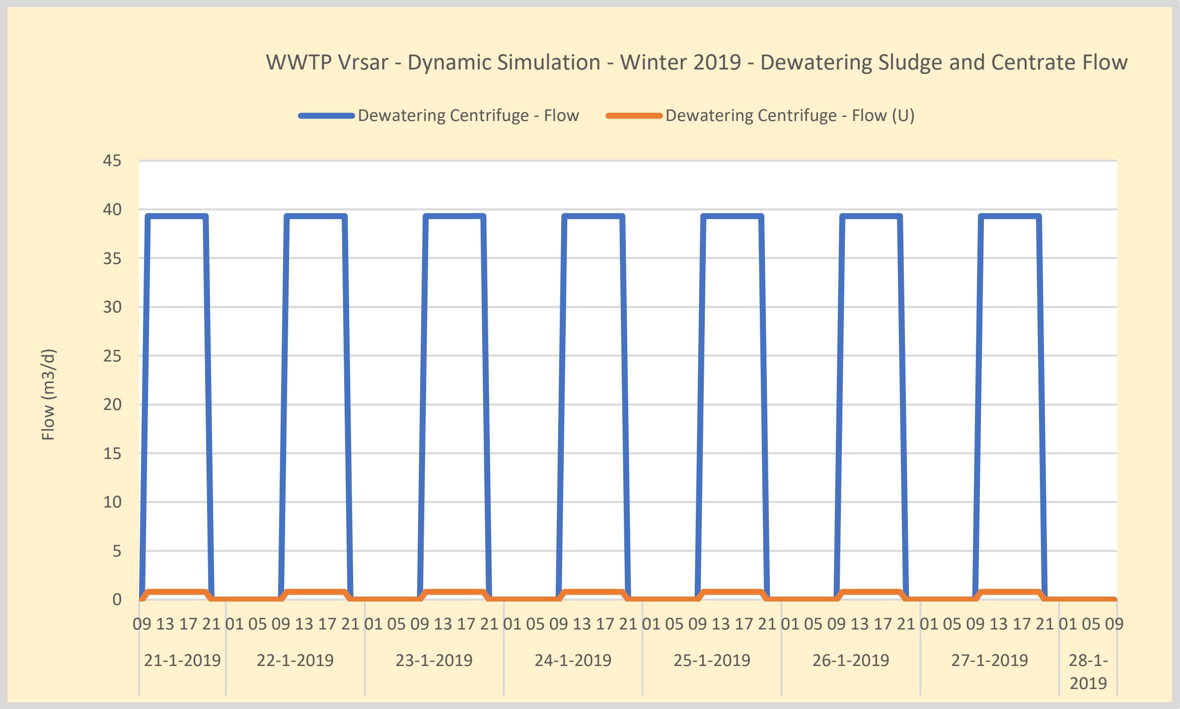


Figure 102. Winter – WWTP Vrsar dewatered sludge and centrate flow.

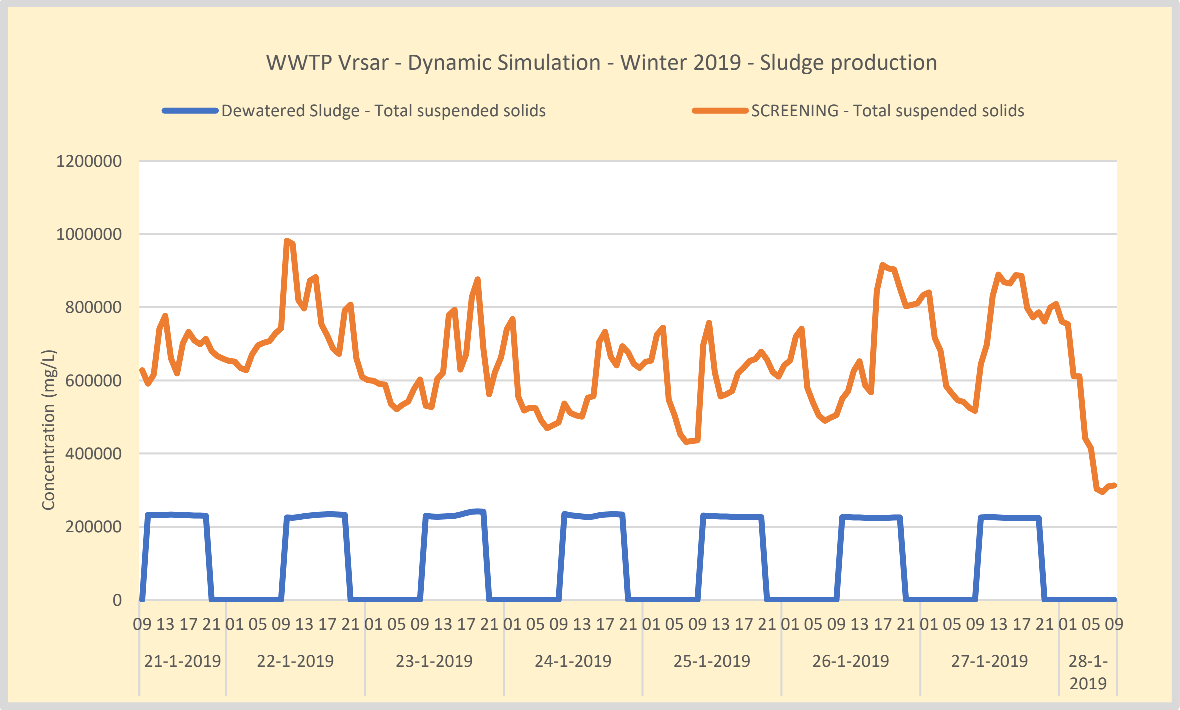


Figure 103. Winter – WWTP Vrsar dewatered sludge and screening sludge concentration. The design assumes dewatered sludge at 23% dry matter. Screening is an estimated concentration as the result of the press operation.

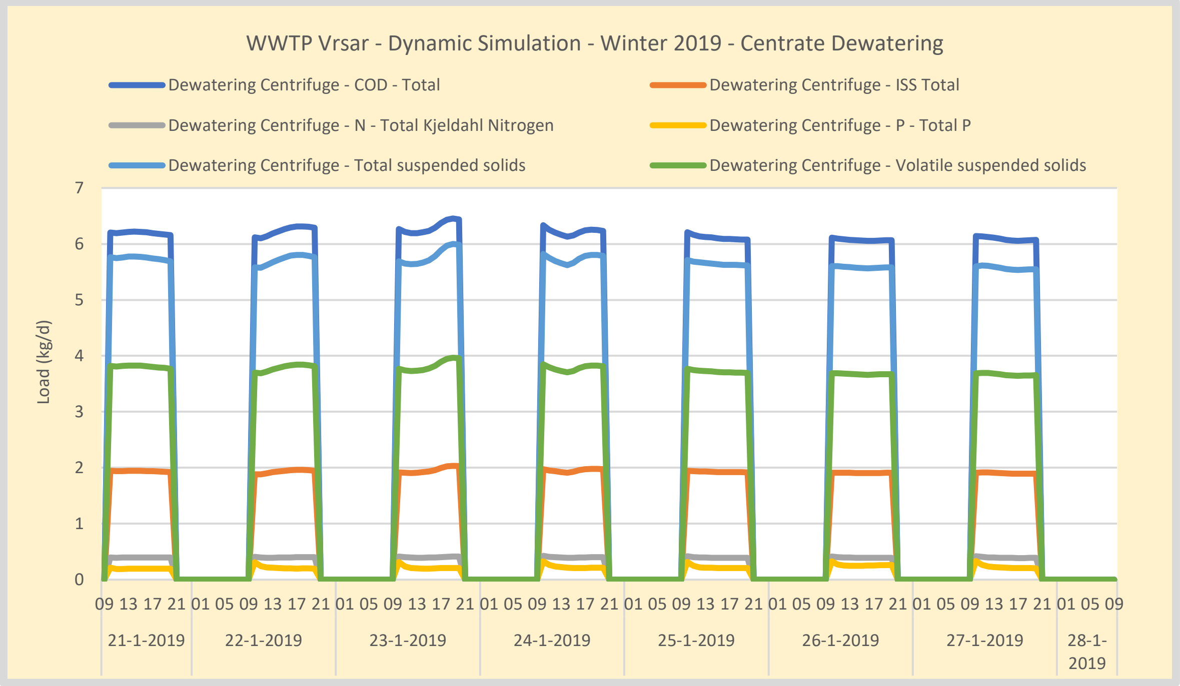


Figure 104. Winter – WWTP Vrsar Centrate load dewatering.

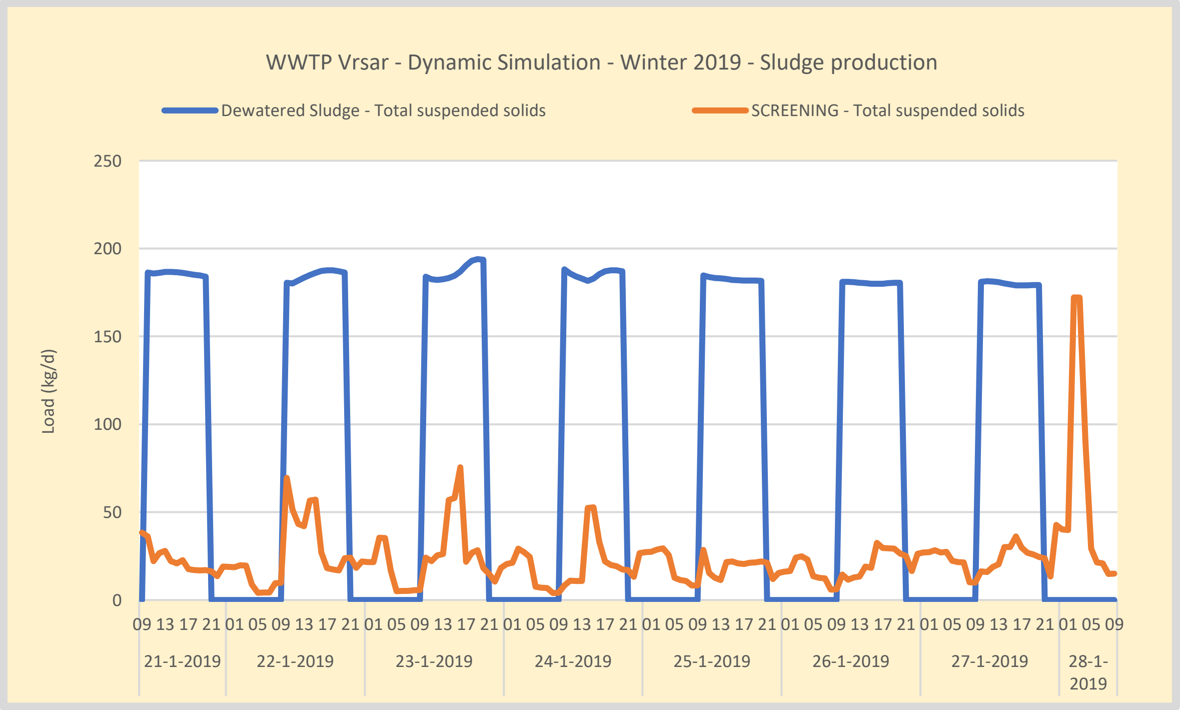


Figure 105. Winter – WWTP Vrsar dewatered sludge load and compacted screening load. Dewatered sludge is operated 10 hours a day at 23%. Screening is produces continuously as a factor of the influent.

7.12 Effluent modelling results

In the figures below the dynamic effluent quality of the plant is presented under winter conditions. The last day included a major rain event. The measurement is coming from the effluent buffer and has a reduced dynamic profile.

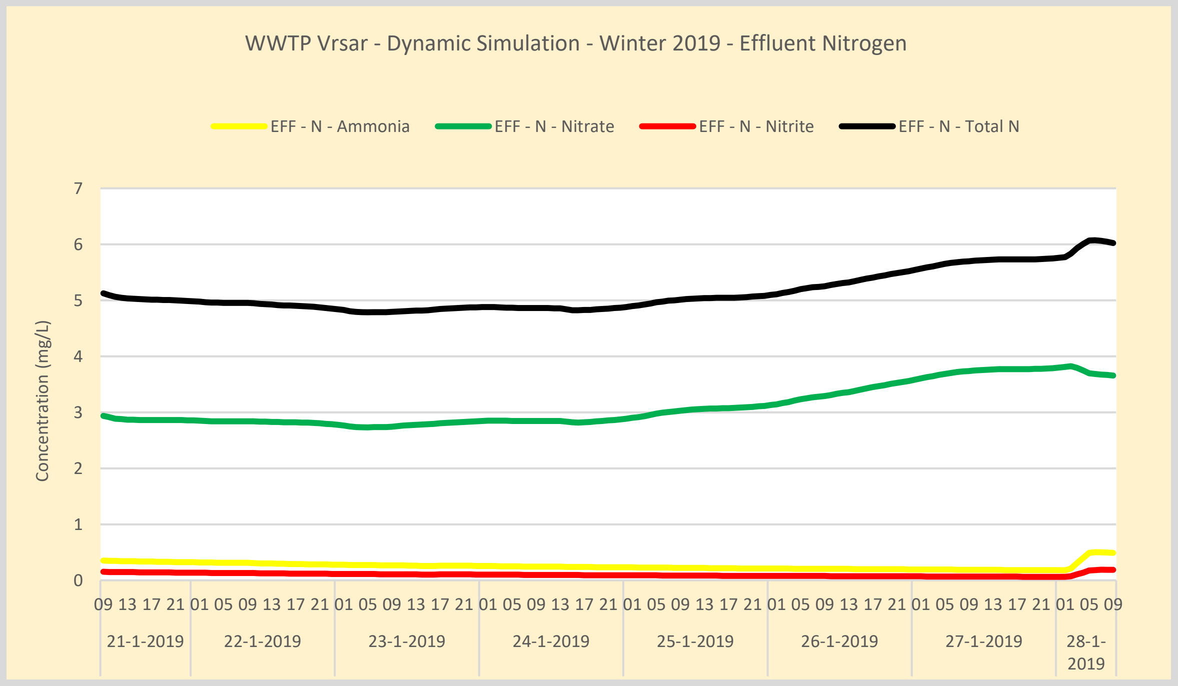


Figure 106. Winter – WWTP Vrsar Effluent nitrogen concentration. Effluent is measured in the outflow of the large effluent buffer.

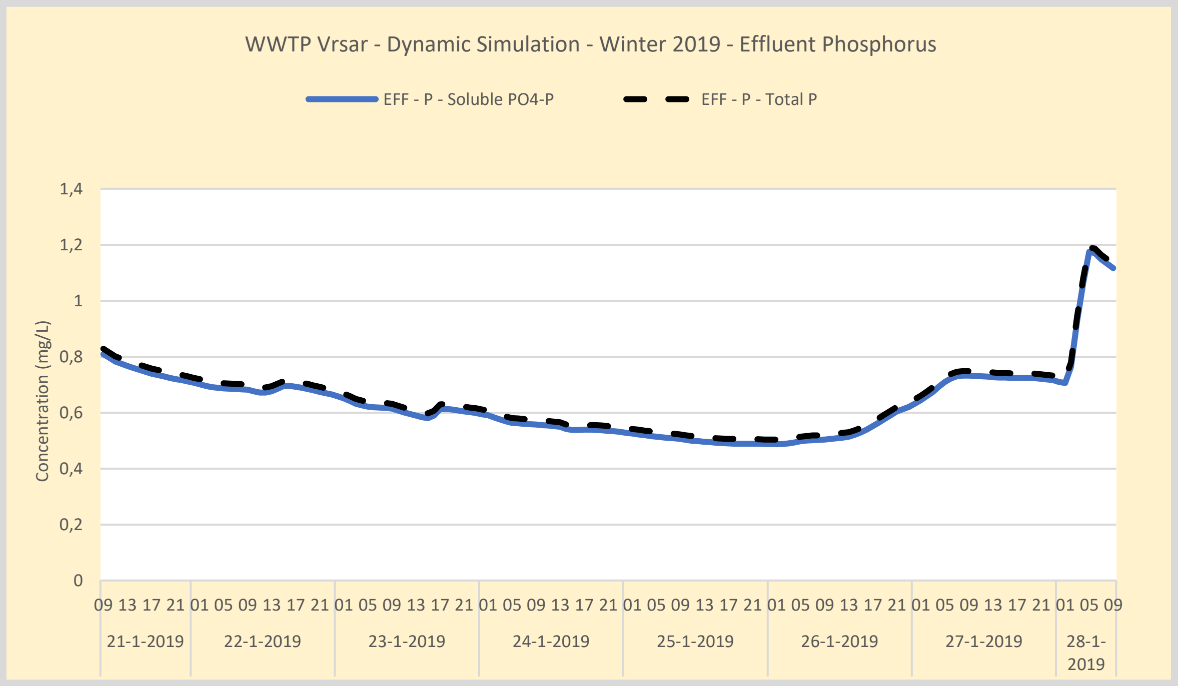


Figure 107. Winter – WWTP Vrsar Effluent phosphorus concentration. Effluent is measured in the outflow of the large effluent buffer.

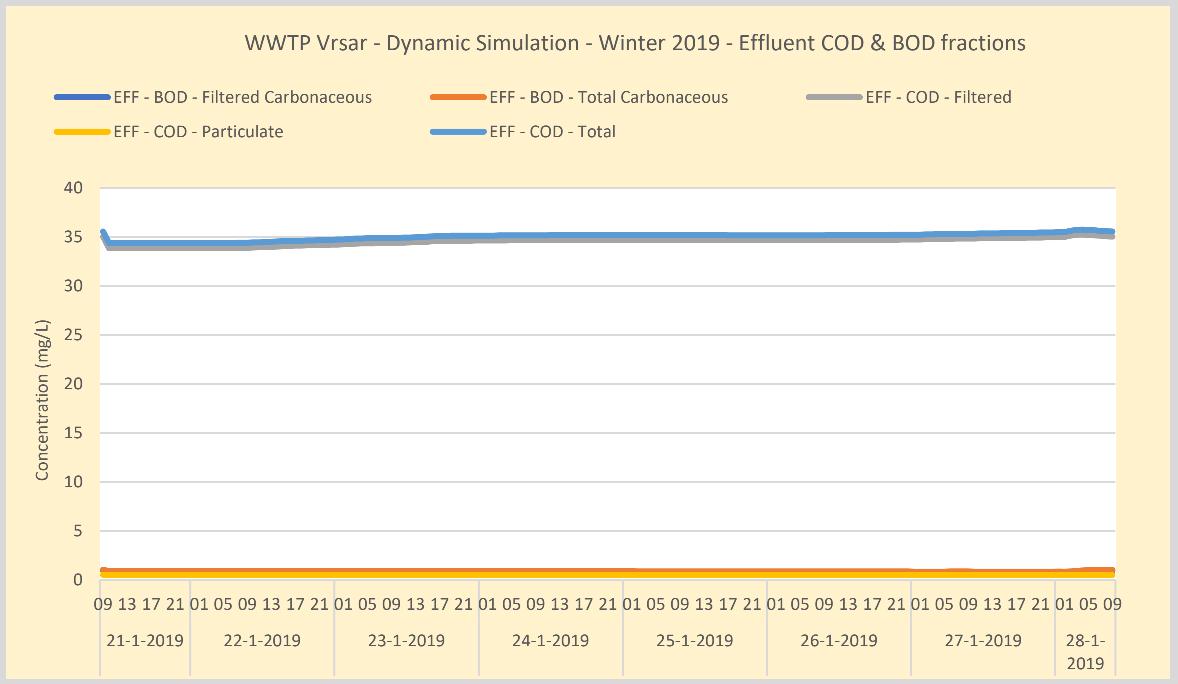


Figure 108. Winter – WWTP Vrsar Effluent COD and BOD concentration. Effluent is measured in the outflow of the large effluent buffer.

7.13 Conclusion dynamic simulations winter period 2019

WWTP Vrsar largely operates according to the design based on the 7-day winter influent measurements performed in 2019. The effluent concentration for all parameters is within the projected effluent limits.

The SRT of the plant during winter is not limiting for nitrification. However, the unaerated (anaerobic and anoxic) volume (HRT) may become too large for the lowest loading conditions. This could negatively affect biological growth and P-removal. Therefore, it is advised to use maximum internal recycle rates to also during the winter low loading conditions. The plant operates without requirement of Iron for P-removal.

The choice of operation is very much determining the plant and effluent results. The selected control strategy for modelling is a simplified strategy however realistic.

The large effluent buffer reduces effluent fluctuations. The trace of solids and colloidal material in the effluent together with the effluent load profiles and flow, can be used for sea water quality modeling in the winter scenario with a fully functional plant.

Winter operation meets the requirements, however, is not typical in respect to a very high SRT, very long anaerobic and anoxic HRT, very high internal recycle rates proportional to the influent and high DO in the activated sludge system.

Specific potential problems of (winter) operation are:

- Application of hydraulic and sludge residence time that are too long.
- CO2 stripping in the aeration and MBR caused by over aeration, a drop in alkalinity and potentially the pH.

- Too low internal recycles causing long anaerobic zones and increased decay of biomass, degeneration of nitrification capacity and degraded Bio-P.
- P-release in the WAS storage tank.
- Too little WAS sludge production (long SRT) to meet the Bio-P requirement.

8 Summer results dynamic modelling

8.1 Summer operation process flow diagram

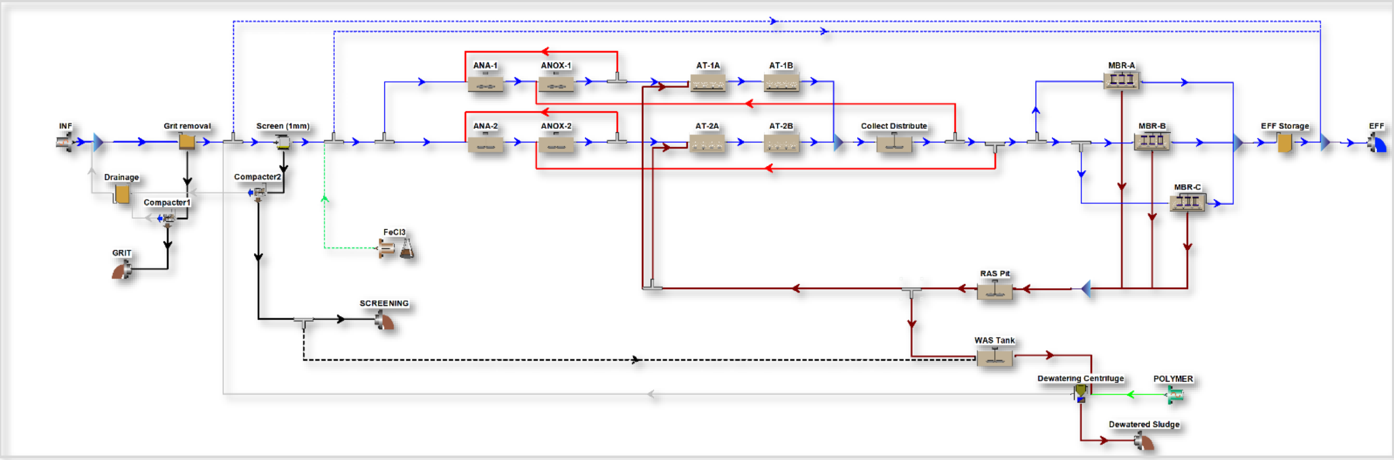


Figure 109. WWTP Vrsar - BioWin model summer operation. One line and one MBR are taken out of operation (dashed lines not operated). Operational adjustments are made to accommodate dynamic modelling. MBR-C is taken out of operation to avoid stripping of alkalinity.

8.2 Performance overview 7-day average

Based on the total dataset including peak loading events and rain events, the average WWTP performance is calculated and presented in the tables below. In average, for the simulated period including rain and peak events and using a simplified process control, the effluent performance and aerobic SRT is in accordance with the design criteria.

Table 10. WWTP Vrsar - Summer 2019 - Dynamic average effluent concentration (mg/L)

WWTP Vrsar - Summer 2019 - Dynamic average effluent concentration (mg/L)			
EFF	Temperature	Concentration	20,0
EFF	COD - Total	Concentration	39,7
EFF	N - Total N	Concentration	5,4
EFF	P - Total P	Concentration	0,5
EFF	Total suspended solids	Concentration	1,0

Table 11. WWTP Vrsar - Summer 2019 - Dynamic average Air flow rate (m3/h)

WWTP Vrsar - Summer 2019 - Dynamic average Air flow rate (m3/h)			
AT-1A	Air flow rate	Flow	156,6
AT-1B	Air flow rate	Flow	422,9
AT-2A	Air flow rate	Flow	156,6
AT-2B	Air flow rate	Flow	422,9
MBR-A	Air flow rate	Flow	300,0
MBR-B	Air flow rate	Flow	300,0
MBR-C	Air flow rate	Flow	300,0

Table 12. WWTP Vrsar - Summer 2019 - Dynamic average Flows (m3/d)

WWTP Vrsar - Summer 2019 - Dynamic average Flows (m3/d)			
ANA-R1	Flow (S)	Flow	1.250,0
ANA-R2	Flow (S)	Flow	1.250,0
ANOX-R1	Flow (S)	Flow	6.968,6
ANOX-R2	Flow (S)	Flow	6.968,6
AS Emergency Bypass	Flow (S)	Flow	0,0
Dewatering Centrifuge	Flow (U)	Flow	1,8
Grit removal	Flow (U)	Flow	1,0
MBR-A	Flow (U)	Flow	3.213,3
MBR-B	Flow (U)	Flow	3.213,3
MBR-C	Flow (U)	Flow	3.213,3
Screen (1mm)	Flow (U)	Flow	0,4
Screen Emergency Bypass	Flow (S)	Flow	0,0
WAS Splitter	Flow (S)	Flow	39,2

Table 13. WWTP Vrsar - Summer 2019 - Dynamic average SRT and HRT

WWTP Vrsar - Summer 2019 - Dynamic average SRT and HRT		
Temperature	20	°C
Average waste sludge production	378,7	kgTSS/d
SRT Total	32,8	d
SRT Aerobic	15,6	d
SRT AT+ANOX	22,2	d
WAS Tank HRT	3,0	hour
ANA HRT to influent	5,1	hour

Table 14. WWTP Vrsar - Summer 2019 - Dynamic average Iron and Polymer (mg/L, kg/d, m3/d)

WWTP Vrsar - Summer 2019 - Dynamic average Iron and Polymer (mg/L & kg/d)			
FeCl3	Flow	Flow	0,0
FeCl3	Total iron (all forms)	Concentration	150.000,0
FeCl3	Total iron (all forms)	Load	0,0
POLYMER	COD - Total	Concentration	18.180,0
POLYMER	COD - Total	Load	8,3
POLYMER	Flow	Flow	0,7

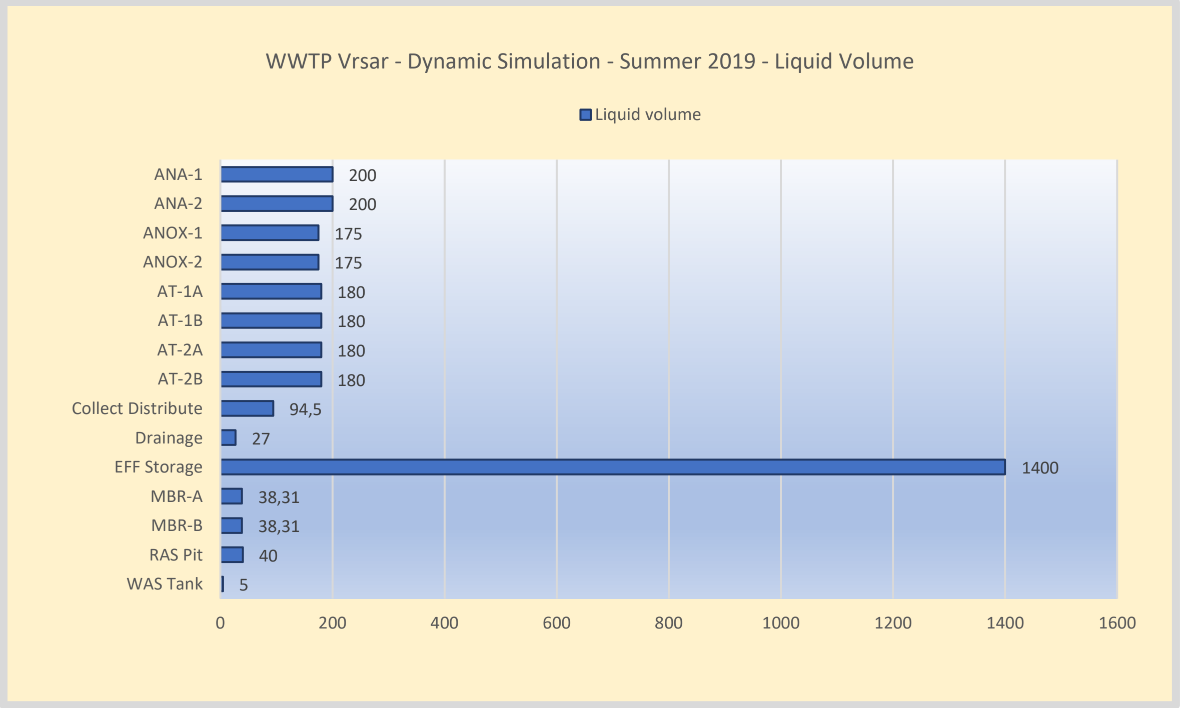


Figure 110. WWTP Vrsar – Volume distribution of modelled reactor elements. The actual WAS tank is 150 m3 however the sludge volume is modelled based on an HRT less than 2,5 hours to avoid P-release. The WAS tank is not suitable for sludge storage.

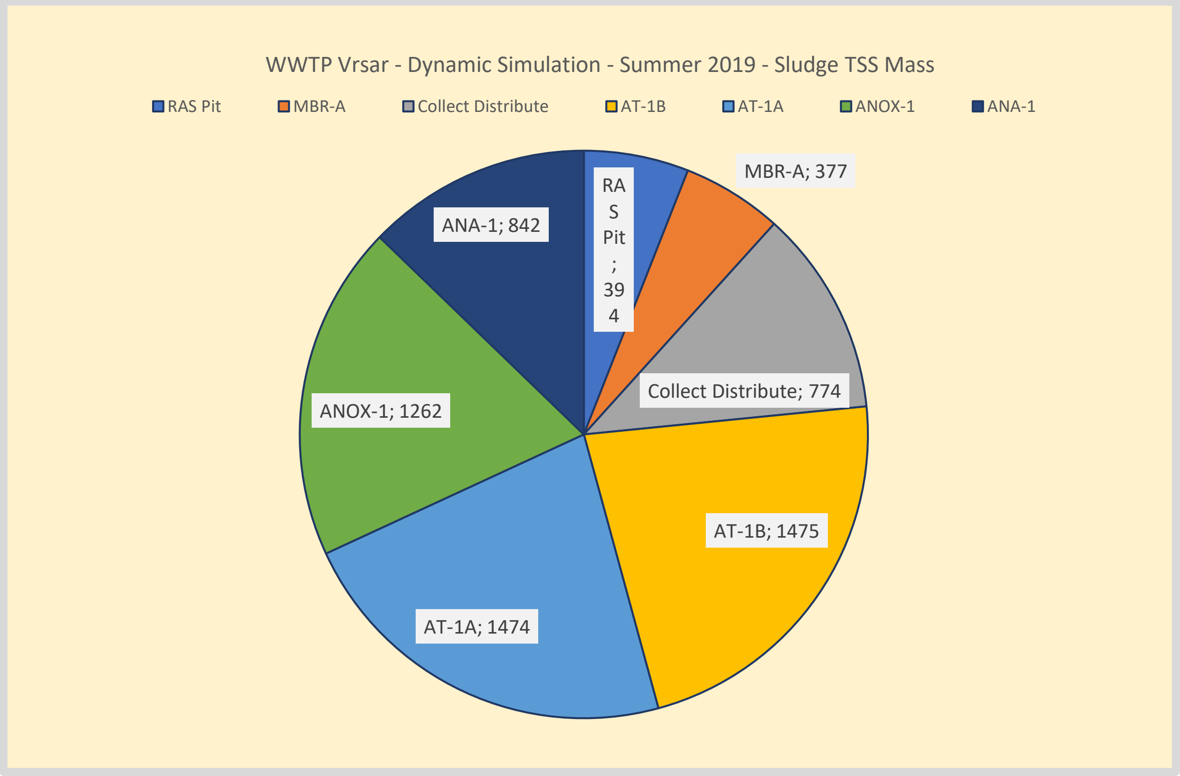
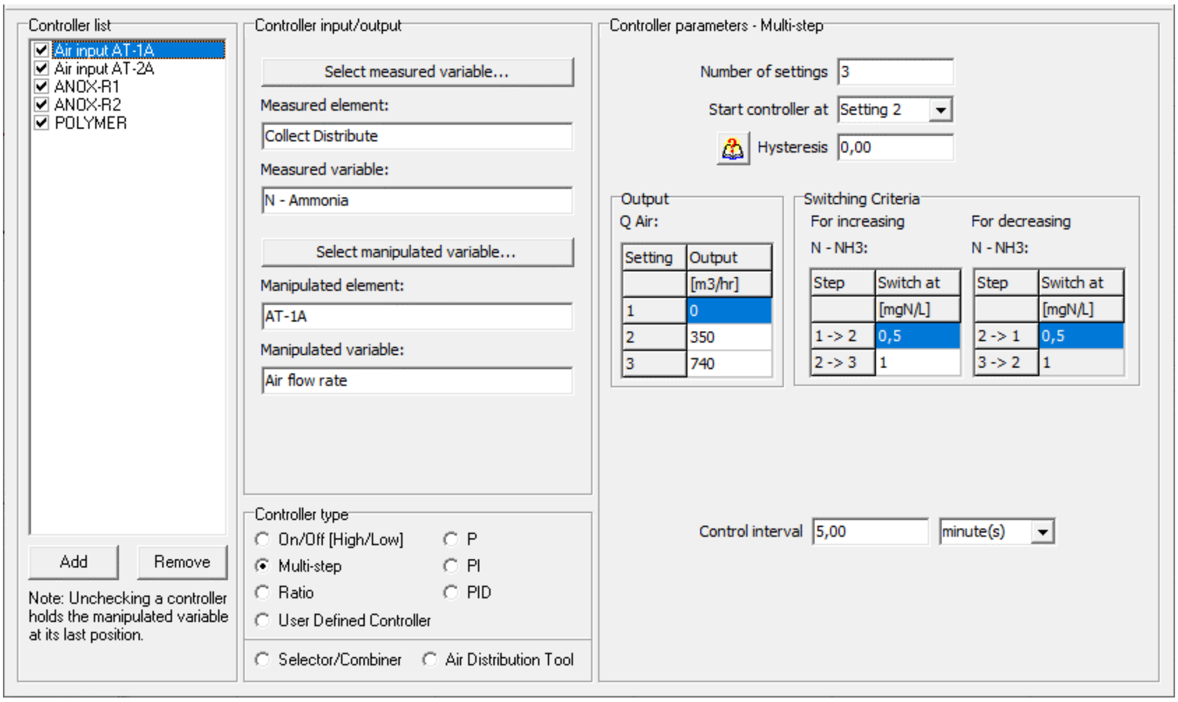


Figure 111. Summer – WWTP Vrsar sludge mass distribution (kgTSS) in the reactor tanks. Based on these data and the average sludge production, the SRT of the WWTP is calculated. All operated reactors containing activated sludge are included in the SRT calculations.

8.3 Summer process controllers.



Controller list:
- ☑ Air input AT-1A
- ☑ Air input AT-2A
- ☑ ANOX-R1
- ☑ ANOX-R2
- ☑ POLYMER

Note: Unchecking a controller holds the manipulated variable at its last position.

Measured element: Collect Distribute
Measured variable: N - Ammonia
Manipulated element: AT-1A
Manipulated variable: Air flow rate

Controller type:
○ On/Off [High/Low] ○ P
● Multi-step ○ PI
○ Ratio ○ PID
○ User Defined Controller
○ Selector/Combiner ○ Air Distribution Tool

Number of settings: 3
Start controller at: Setting 2
Hysteresis: 0,00

Output
Q Air:

Setting	Output [m3/hr]
1	0
2	350
3	740

Switching Criteria
For increasing
N - NH3:

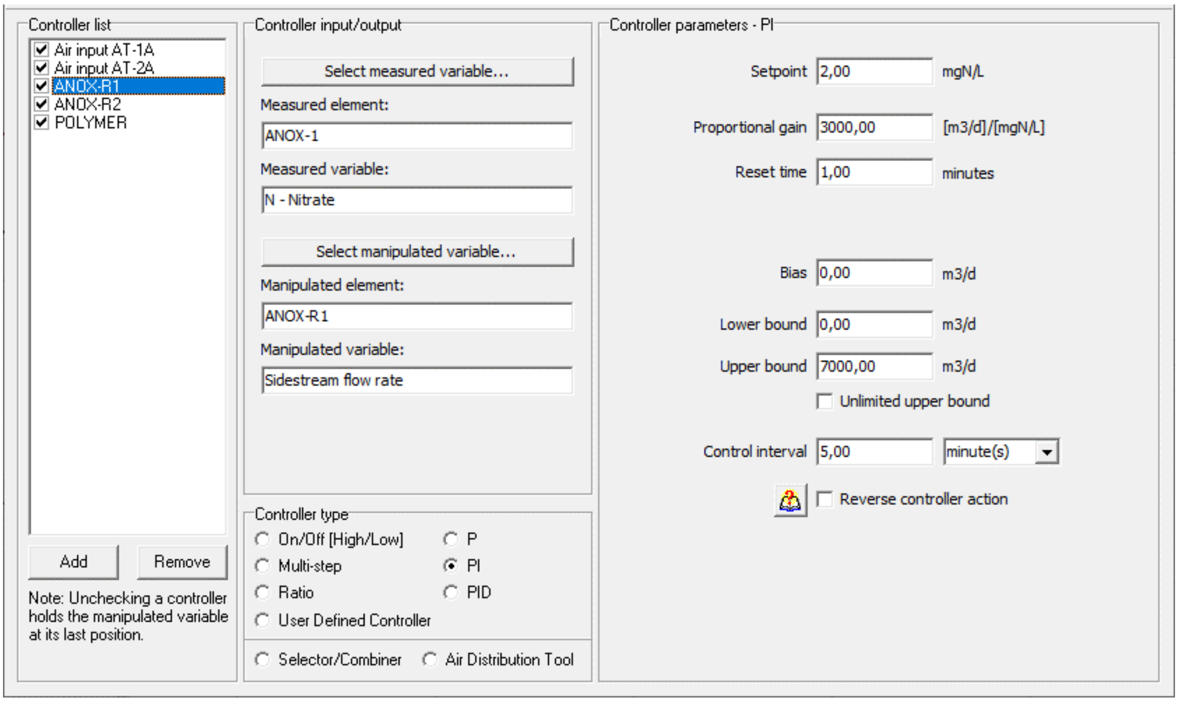
Step	Switch at [mgN/L]
1 -> 2	0,5
2 -> 3	1

For decreasing
N - NH3:

Step	Switch at [mgN/L]
2 -> 1	0,5
3 -> 2	1

Control interval: 5,00 minute(s)

Figure 112. Summer – WWTP Vrsar BioWin controller toolbox used for controlling the air input of AT-A. The measured variable is NH4 in the collect distribute tank. The manipulated variable the air flow in AT-A. There are 3 settings for the air flow depending on the NH4 concentration.



Controller list:
- ☑ Air input AT-1A
- ☑ Air input AT-2A
- ☑ ANOX-R1
- ☑ ANOX-R2
- ☑ POLYMER

Note: Unchecking a controller holds the manipulated variable at its last position.

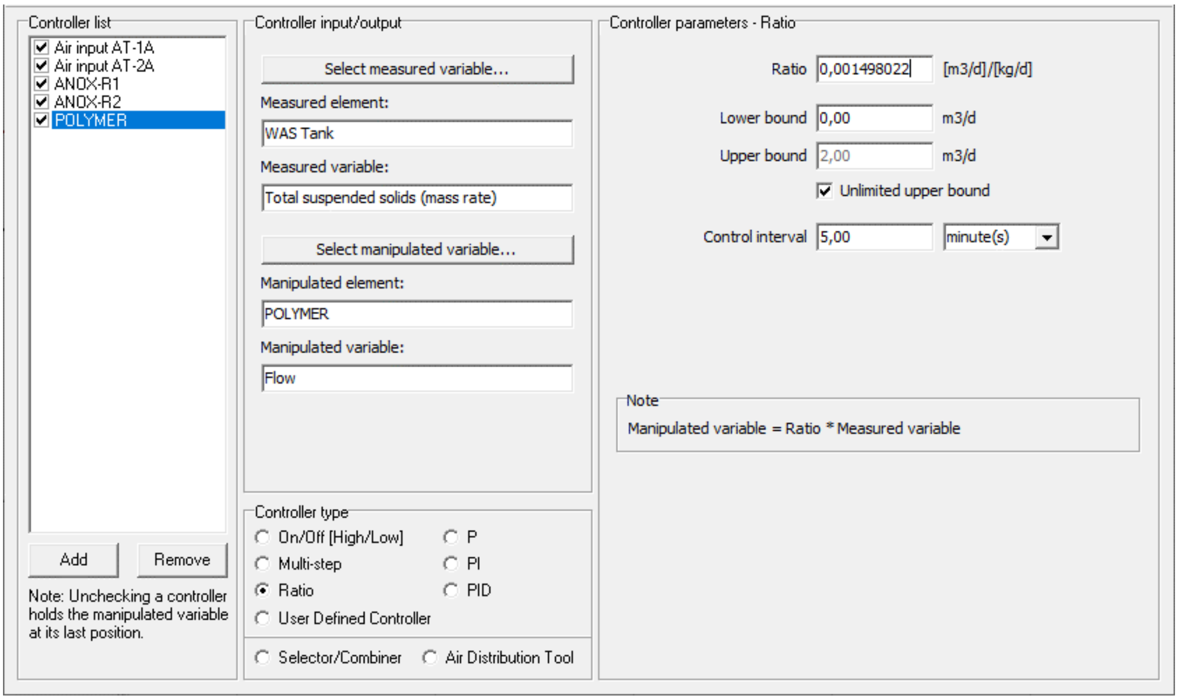
Measured element: ANOX-1
Measured variable: N - Nitrate
Manipulated element: ANOX-R1
Manipulated variable: Sidestream flow rate

Controller type:
○ On/Off [High/Low] ○ P
○ Multi-step ● PI
○ Ratio ○ PID
○ User Defined Controller
○ Selector/Combiner ○ Air Distribution Tool

Setpoint: 2,00 mgN/L
Proportional gain: 3000,00 [m3/d]/[mgN/L]
Reset time: 1,00 minutes
Bias: 0,00 m3/d
Lower bound: 0,00 m3/d
Upper bound: 7000,00 m3/d
☐ Unlimited upper bound
Control interval: 5,00 minute(s)
☐ Reverse controller action

Figure 113. Summer – WWTP Vrsar BioWin controller toolbox used for controlling the anoxic recycle ANOX-R. Indicated are the measured variable being NO3 in the anoxic tank and

manipulated variable the recycle flow ANOX-R. The PI controller has an upper bound of 7.000 m3/d equal to the maximum installed pump capacity per lane.



☑ Air input AT-1A
☑ Air input AT-2A
☑ ANOX-R1
☑ ANOX-R2
☑ POLYMER

Measured element: WAS Tank
Measured variable: Total suspended solids (mass rate)
Manipulated element: POLYMER
Manipulated variable: Flow

Ratio 0,001498022 [m3/d]/[kg/d]
Lower bound 0,00 m3/d
Upper bound 2,00 m3/d
☑ Unlimited upper bound
Control interval 5,00 minute(s)

Note
Manipulated variable = Ratio * Measured variable

Controller type
○ On/Off [High/Low] ○ P
○ Multi-step ○ PI
● Ratio ○ PID
○ User Defined Controller
○ Selector/Combiner ○ Air Distribution Tool

Note: Unchecking a controller holds the manipulated variable at its last position.

Figure 114. Summer – WWTP Vrsar BioWin controller toolbox used for controlling the polymer dosage of the dewatering. Indicated are the measured variable being the TSS load entering the dewatering and manipulated variable the PE flow. The applied control ratio is 8 kg PE per 1000 kg TSS based on dry weight. PE is assumed to be particulate substrate with a COD/VSS ratio of 1,42.

8.4 Influent modelling results

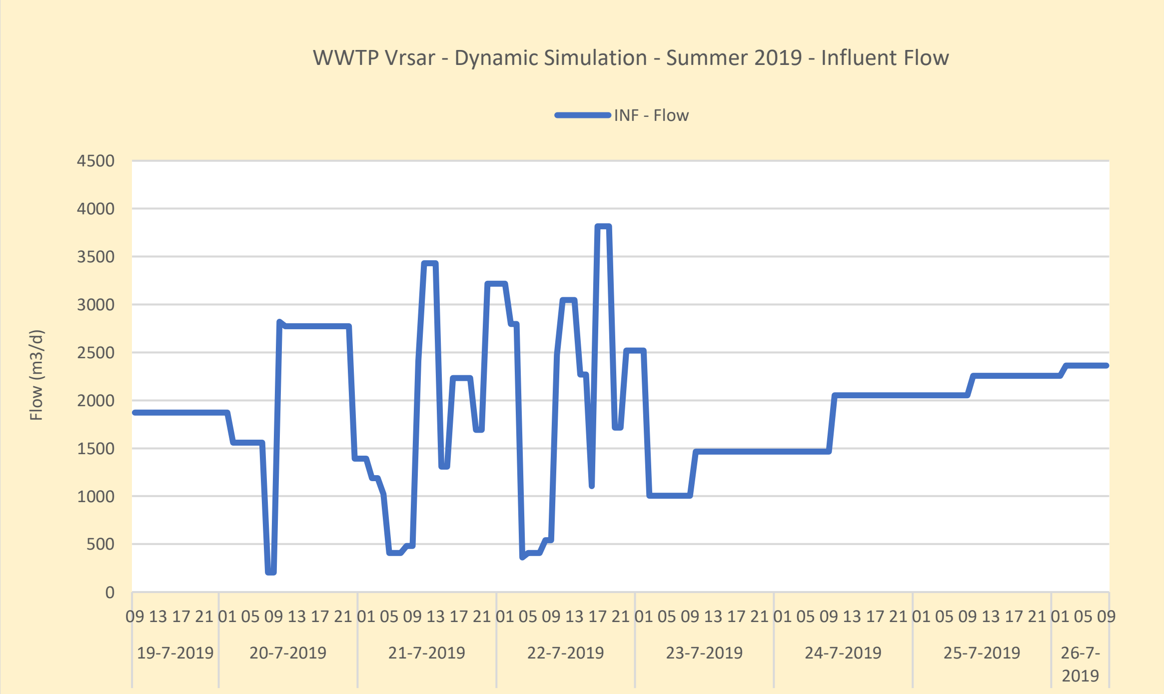


Figure 115. Summer – WWTP Vrsar Influent flow. No rain event occurred.

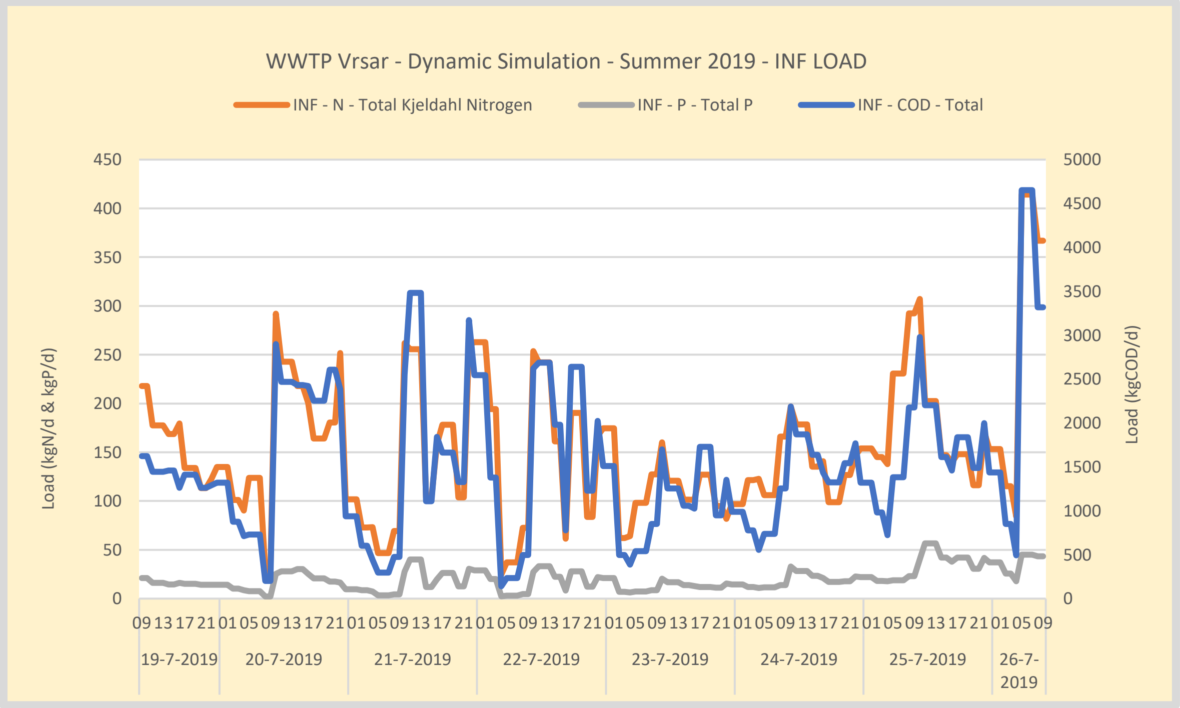


Figure 116. Summer – WWTP Vrsar Influent loads COD, TKN and TP. No rain event occurred.

8.5 Process and recycle flows modelling results

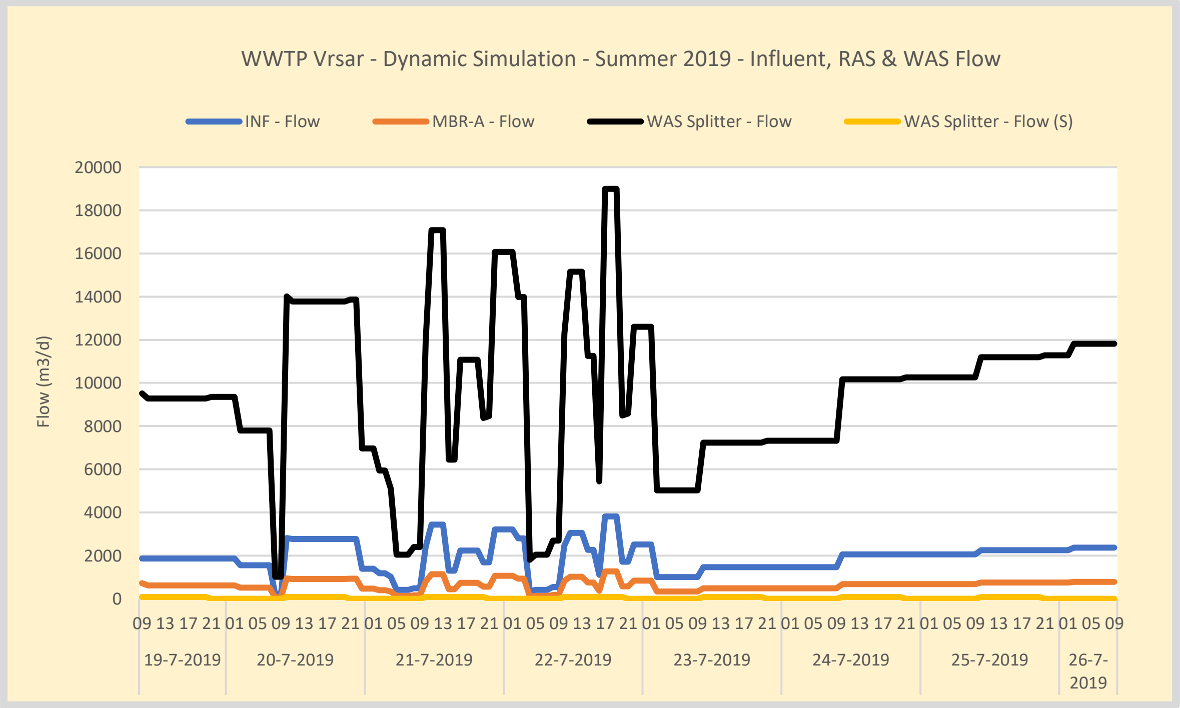


Figure 117. Summer – WWTP Vrsar flow rate settings and control. The MLSS sludge return flow is controlled proportional to the influent. The WAS flow is time controlled and operated 10 hours a day on a constant flow.

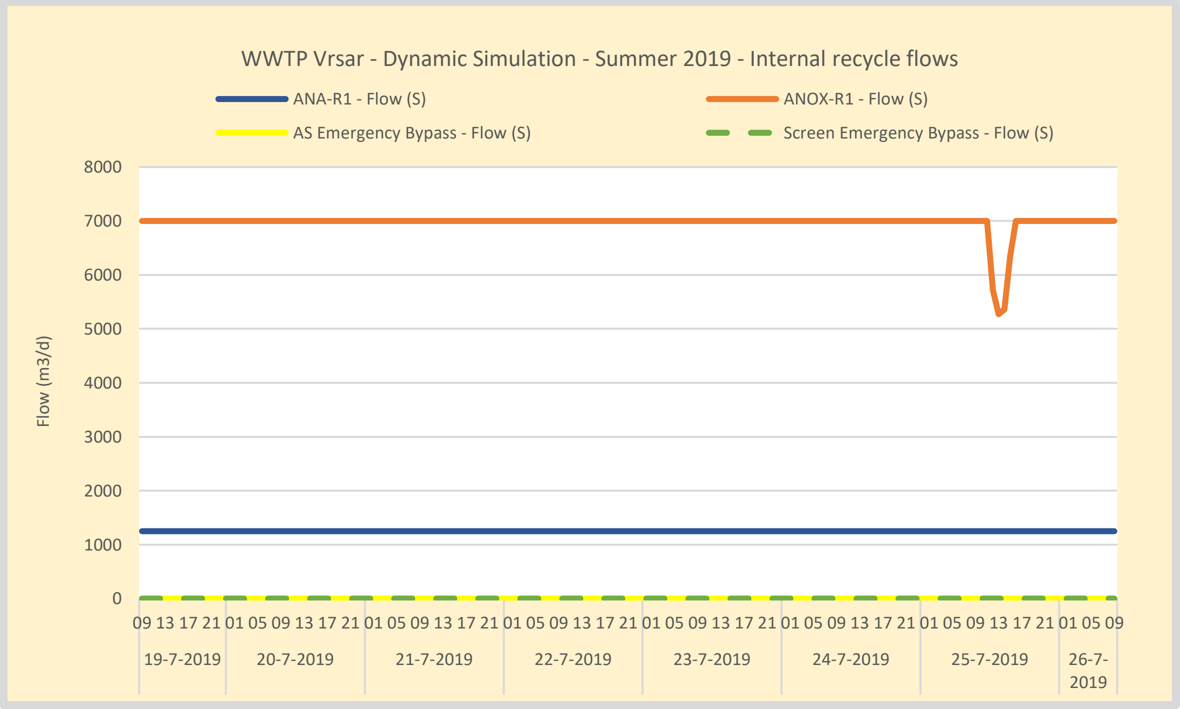


Figure 118. Summer – WWTP Vrsar flow rate settings and control. The bypasses are not used. The anoxic recycle is controlled based on nitrate in the anoxic tank. The flow is reduced when Nitrate becomes higher than 2 mgNO3/L. The fact that this setpoint cannot be reached, indicates the recycle is limiting or that the anoxic tank is too large.

8.6 Waterline operation modelling results

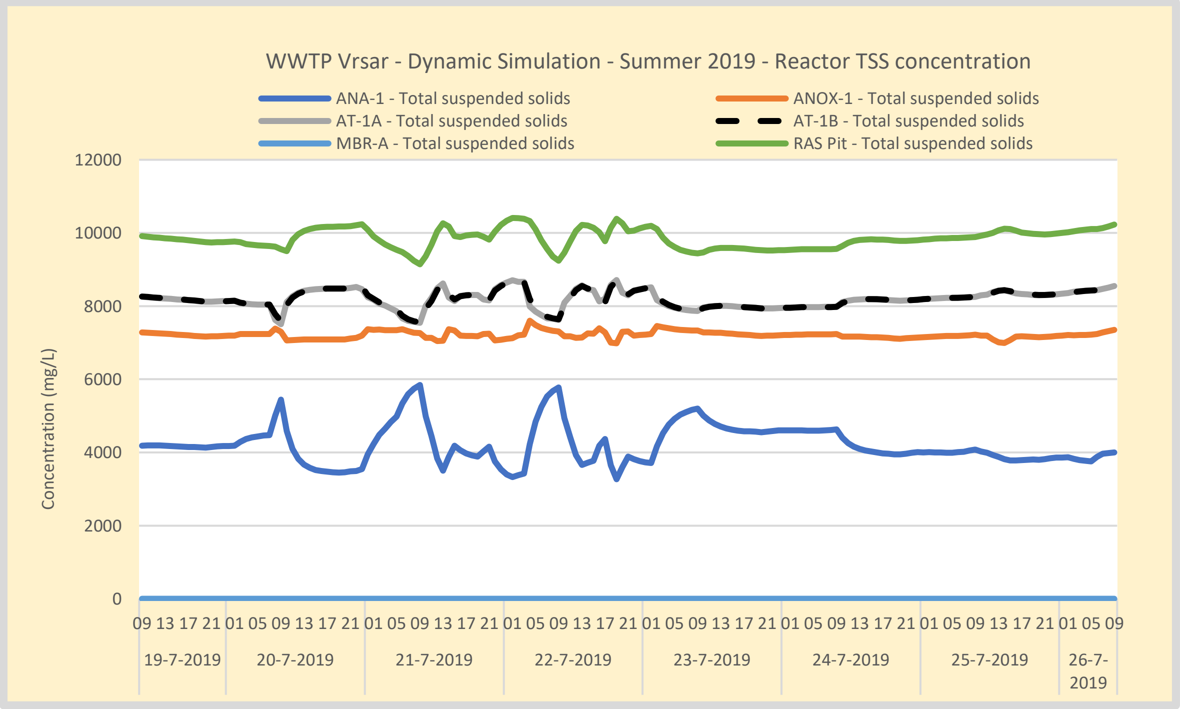


Figure 119. Summer – WWTP Vrsar TSS profile in the waterline. TSS in the MBR is controlled on approximately 10 gTSS/L. TSS is controlled by adjusting the WAS flow and by maintaining a high MLSS recycle from the MBR. SRT is sufficient for summer operation and according to the design.

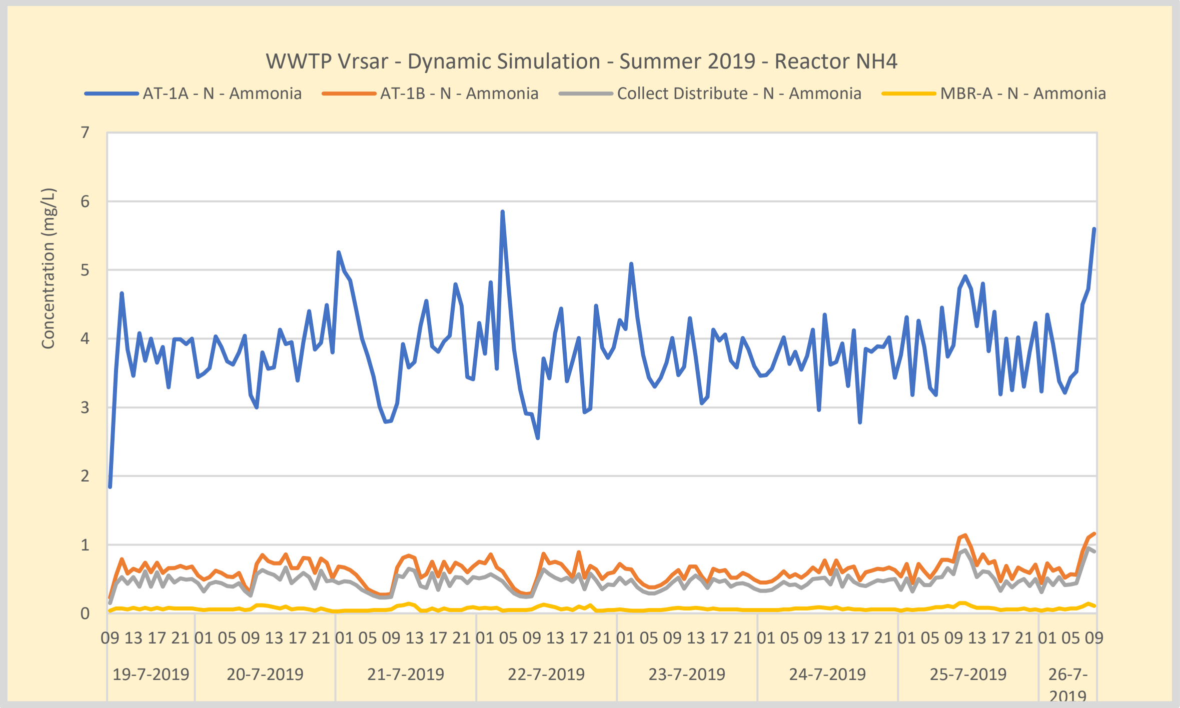


Figure 120. Summer – WWTP Vrsar ammonium profile in the waterline. The air input of AT-A is controlled based on NH4 measured in the collect distribute tank using a 3-step controller. Above 1,0 mgNH4/L the air input goes to its maximum value. Below 0,5 air shuts off. AT-B is DO controlled on 2,0 mgO2/L.

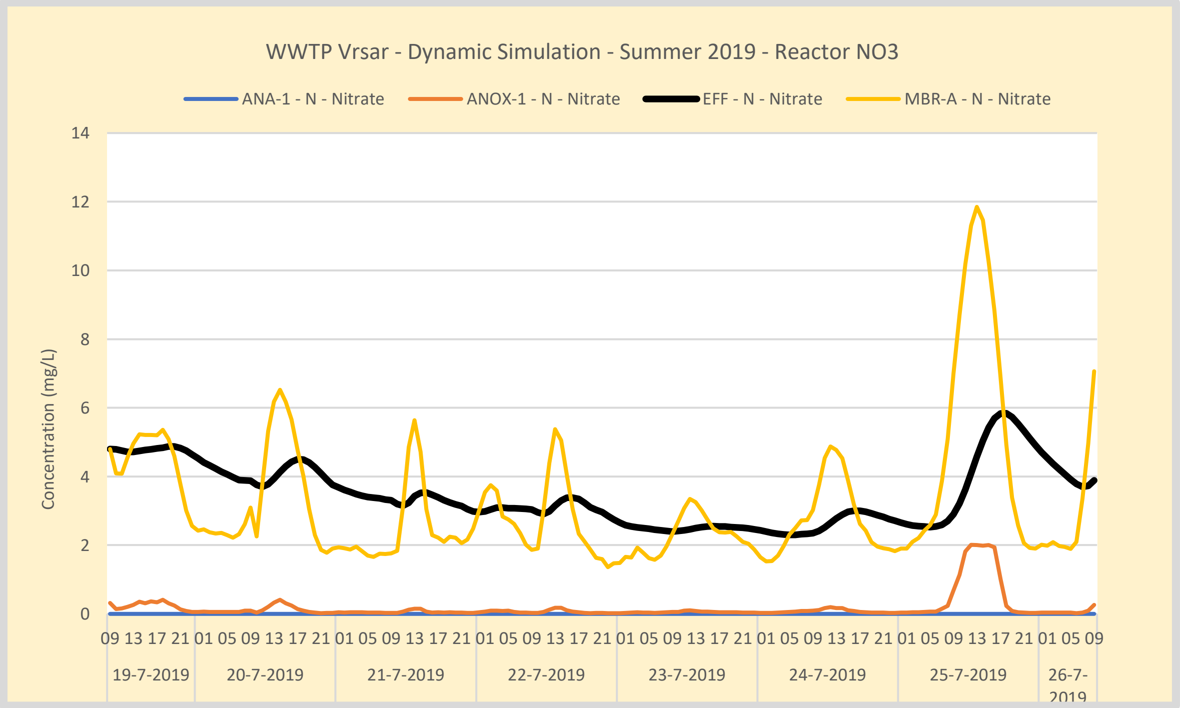


Figure 121. Summer – WWTP Vrsar nitrate in the anoxic tank. The anoxic recycle rate is controlled on a nitrate setpoint of 2 mgNO3/L in the anoxic tank. Internal recycle capacity is not sufficient to reach this setpoint.

8.7 Waterline concentration profiles modelling results

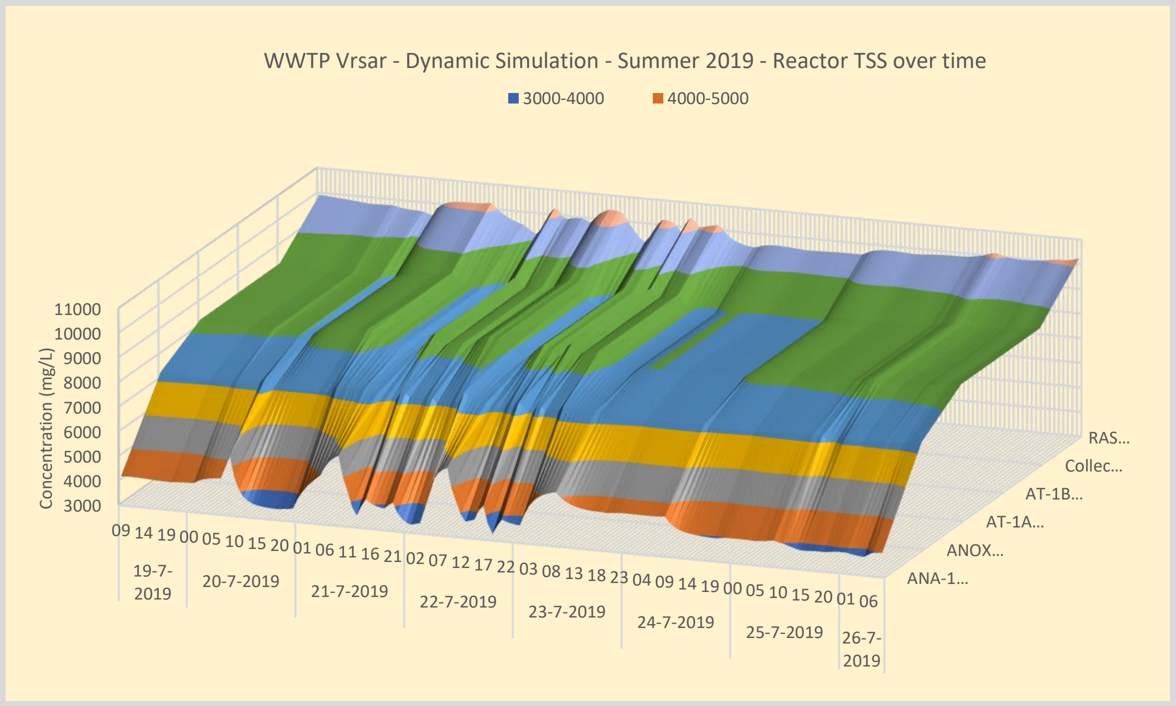


Figure 122. Summer – WWTP Vrsar TSS concentration profile over the waterline.

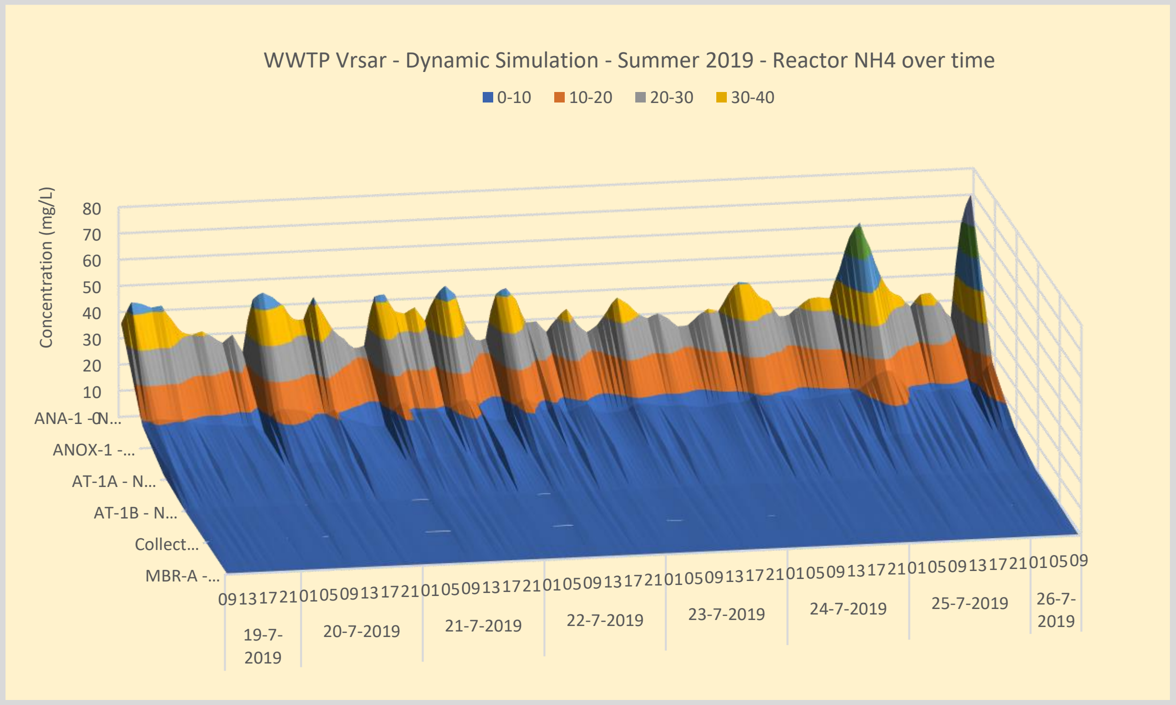


Figure 123. Summer – WWTP Vrsar NH4 concentration profile over the waterline.

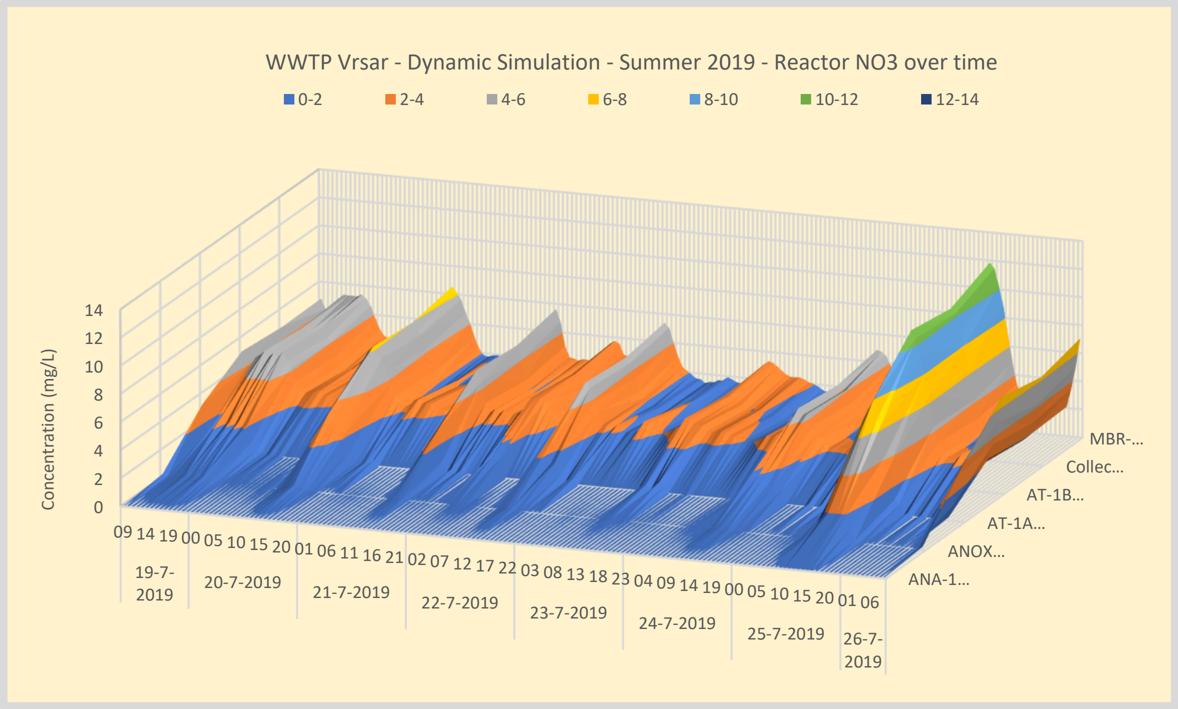


Figure 124. Summer – WWTP Vrsar NO3 concentration profile over the waterline.

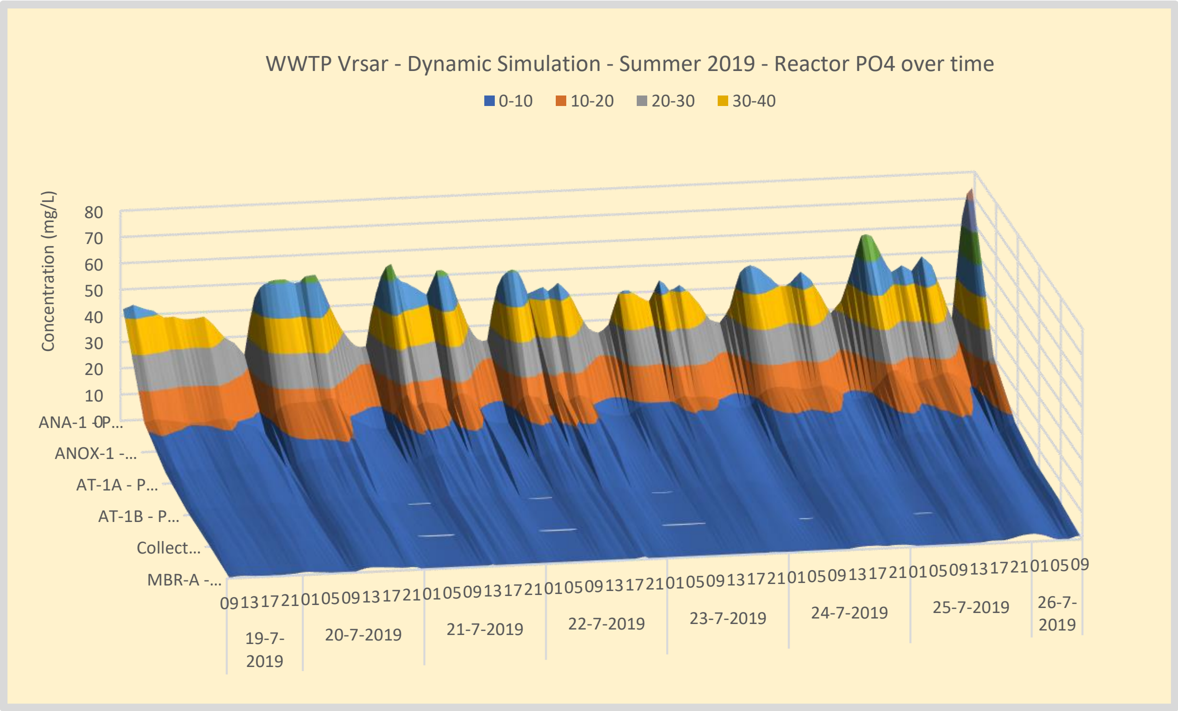


Figure 125. Summer – WWTP Vrsar PO4 concentration profile over the waterline.

8.8 Aeration and DO concentration modelling results

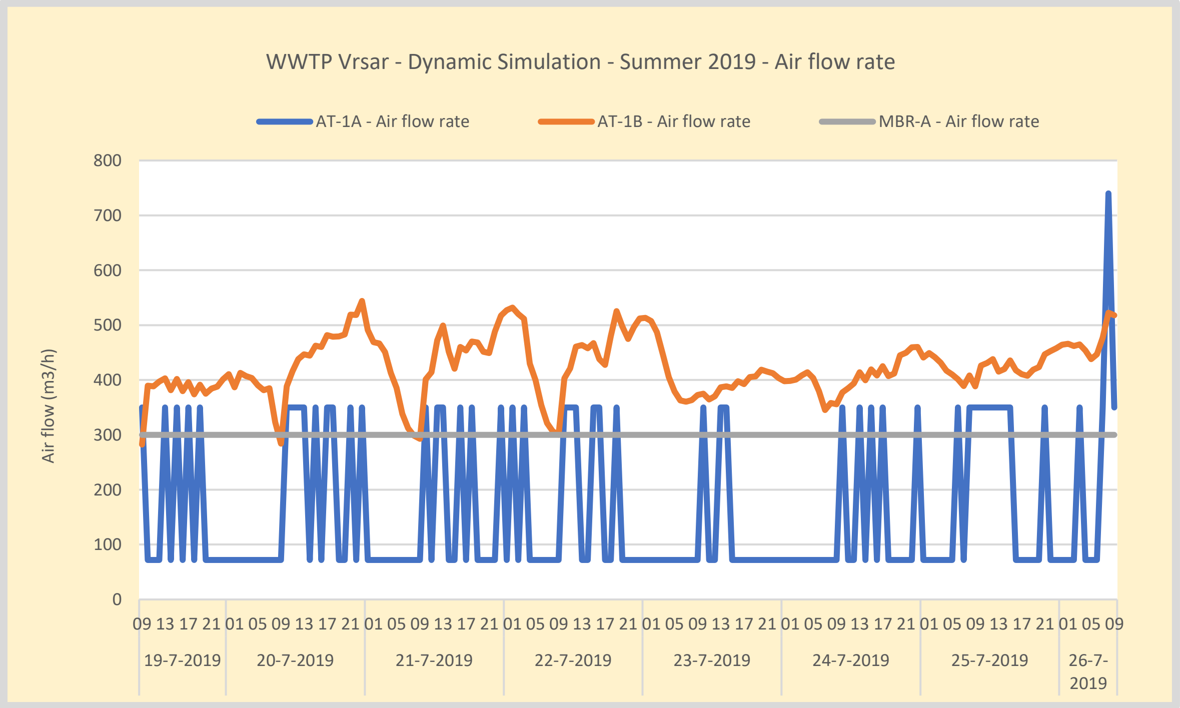


Figure 126. Summer – WWTP Vrsar air input in the different aerated reactors. AT-A is step controlled on NH4, AT-B is setpoint controlled on the DO, the MBR is fully aerated according to the design value.

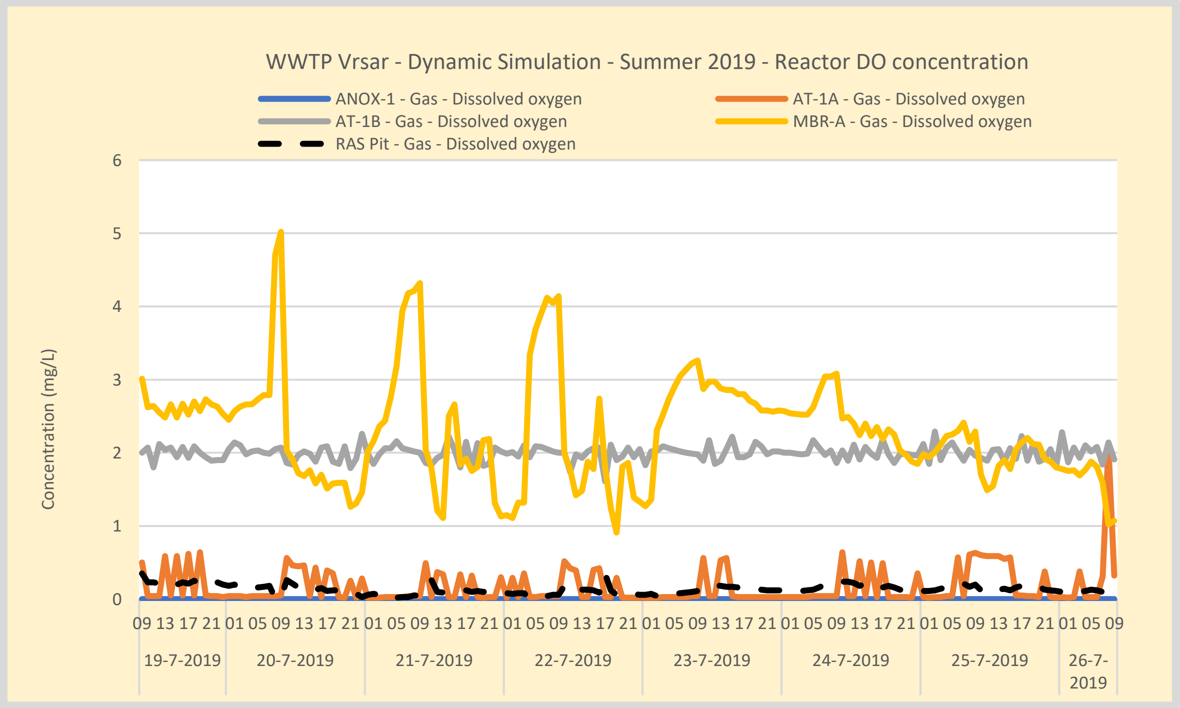


Figure 127. Summer – WWTP Vrsar DO concentration gradients. DO is controlled in the AT-B on 2 mgO2/L and the air flow of AT-B on NH4 concentration in the outflow of the aeration. In the MBR the DO is the result of the designed maximum air input. Little oxygen is recycled over the reactors and little oxygen is measured in the anoxic zone. The DO setpoint can be maintained based on the designed air flow.

8.9 pH and alkalinity modelling results

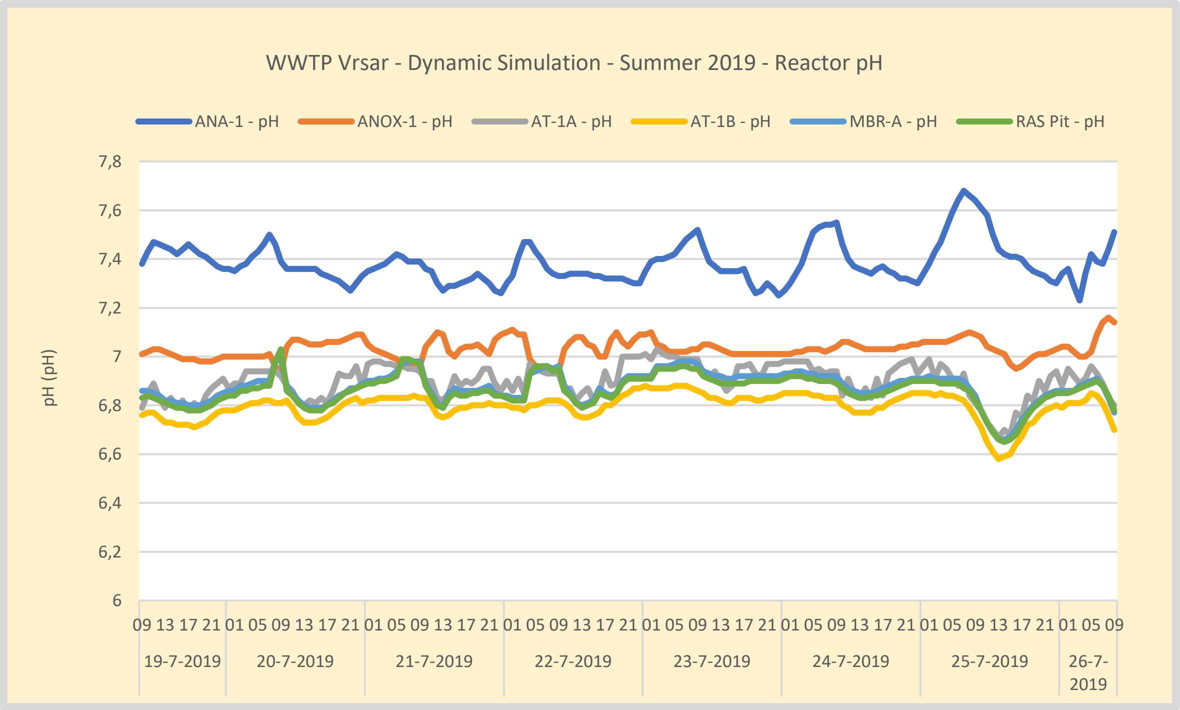


Figure 128. Summer – WWTP Vrsar pH profile over the activated sludge reactors. Influent pH is measured continuously and is not limiting. pH is not limiting.

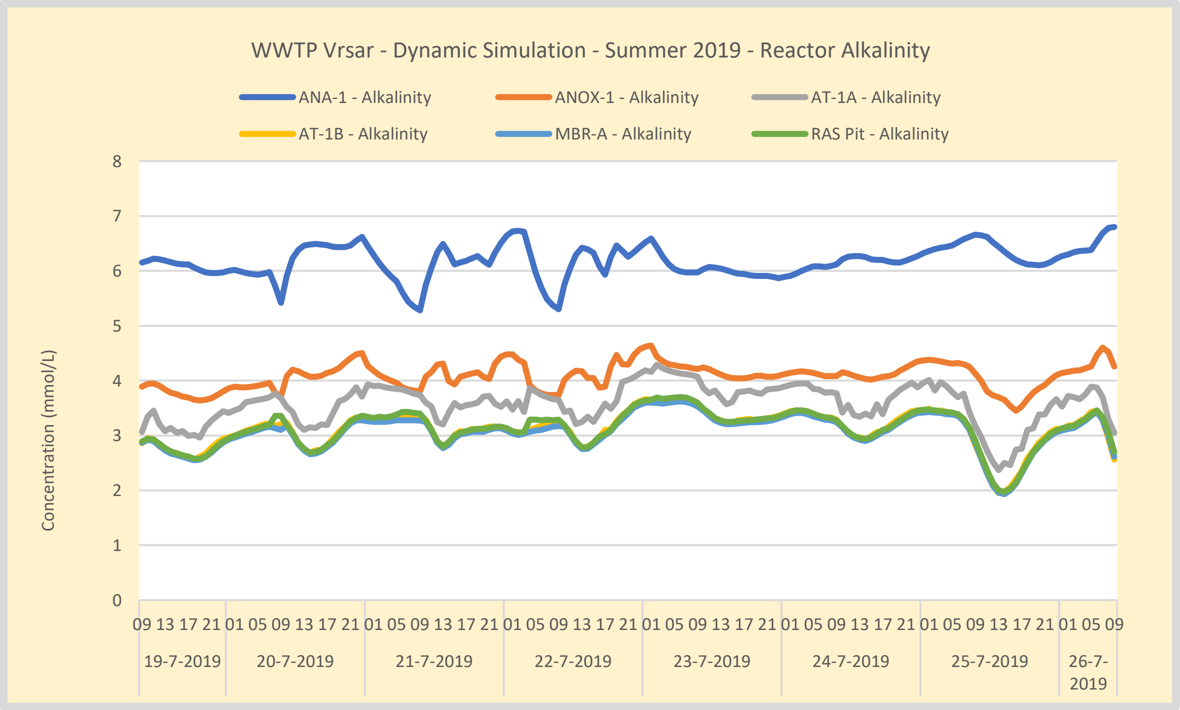


Figure 129. Summer – WWTP Vrsar alkalinity profile over the activated sludge reactors. Influent alkalinity is estimated from local drinking water quality measurements at 7,46 mmol/L. Alkalinity is not becoming zero however potentially limiting under the operated conditions.

8.10 Chemical load and flow modelling results

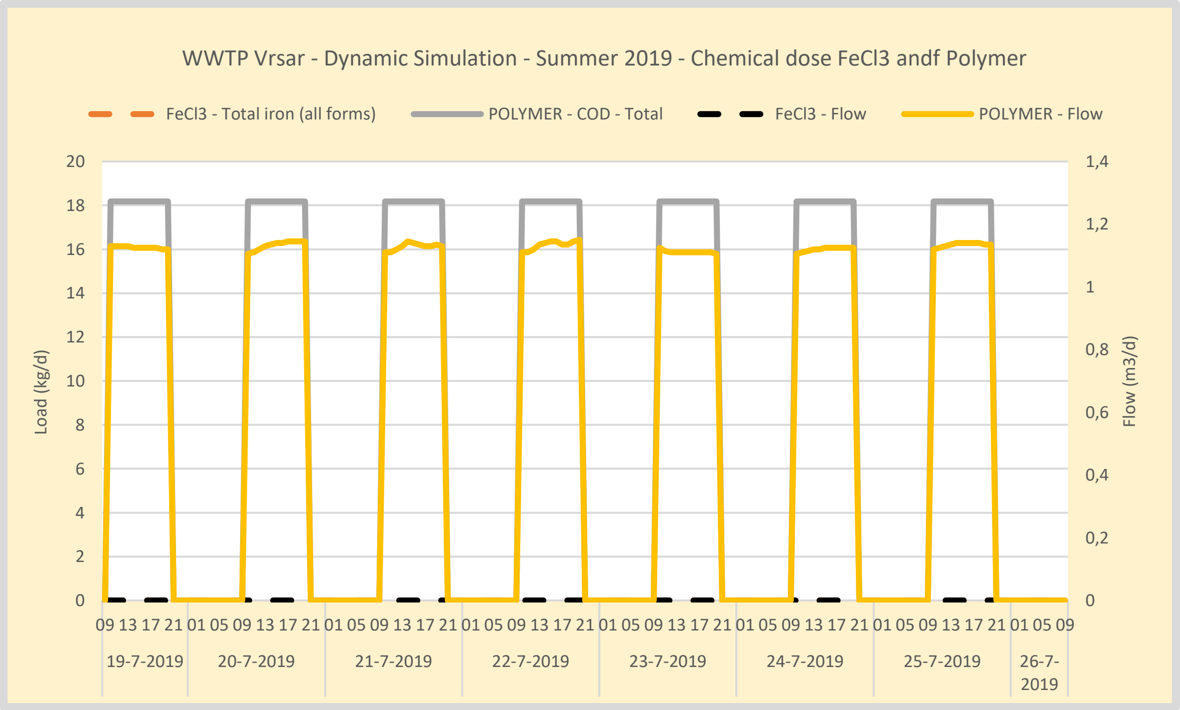


Figure 130. Summer – WWTP Vrsar load and flow of Iron and PE. No iron is dosed. PE is assumed particulate biodegradable COD with a COD/VSS ratio of 1,42 gCOD/gTSS and dosed proportional to the WAS load based on 8 kg PE (dry weight) dosed per 1000 kg WAS (dry weight) flowing in the dewatering.

8.11 Sludge line operation modelling results

In the figures below the dynamic operation of the sludge line including dynamic WAS control and dewatering during 10 hours per day.

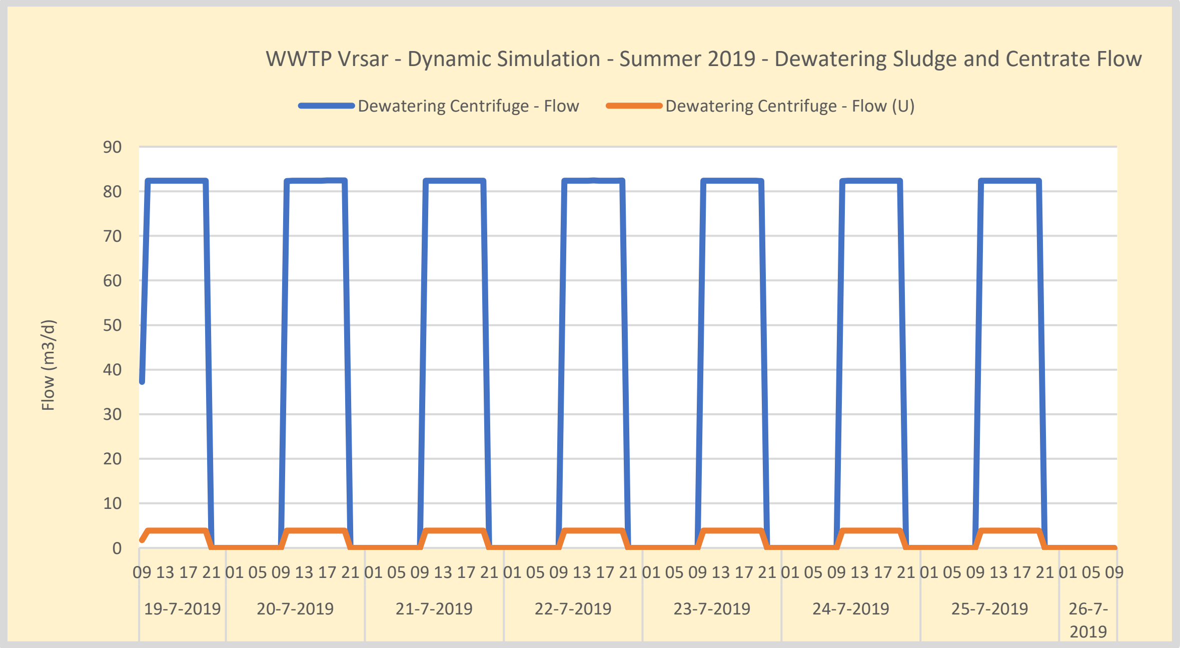


Figure 131. Summer – WWTP Vrsar dewatered sludge and centrate flow.

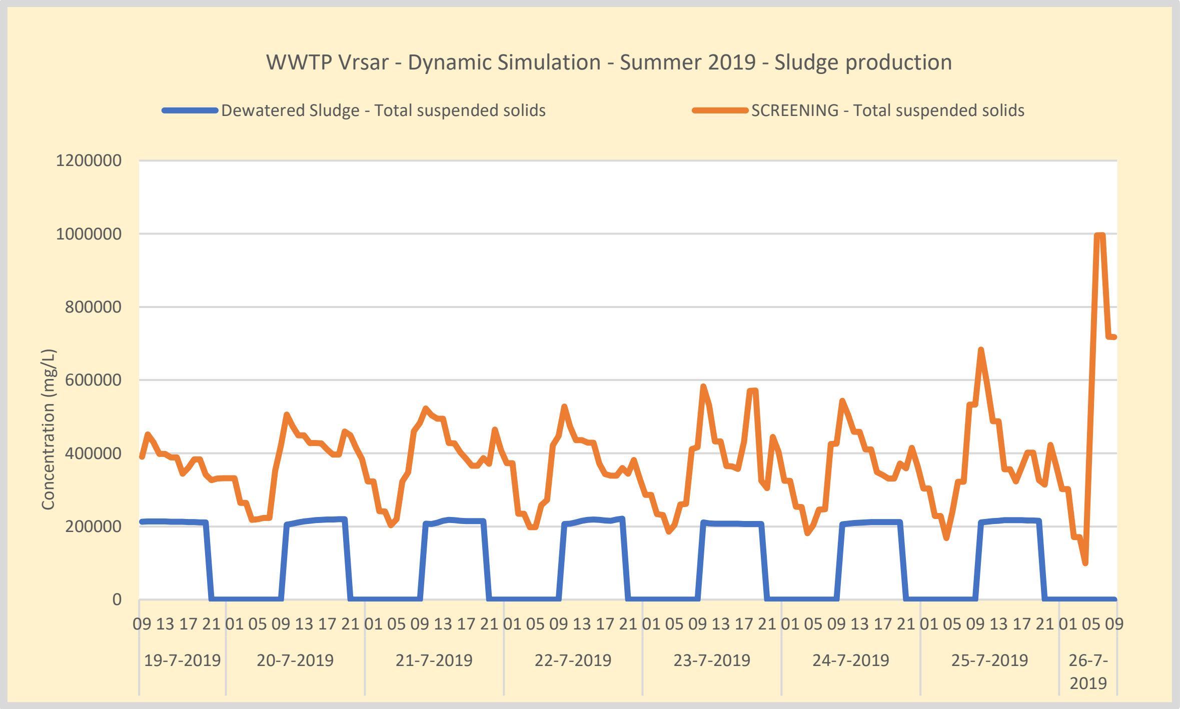


Figure 132. Summer – WWTP Vrsar dewatered sludge and screening sludge concentration. The design assumes dewatered sludge at 23% dry matter. Screening is an estimated concentration as the result of the press operation.

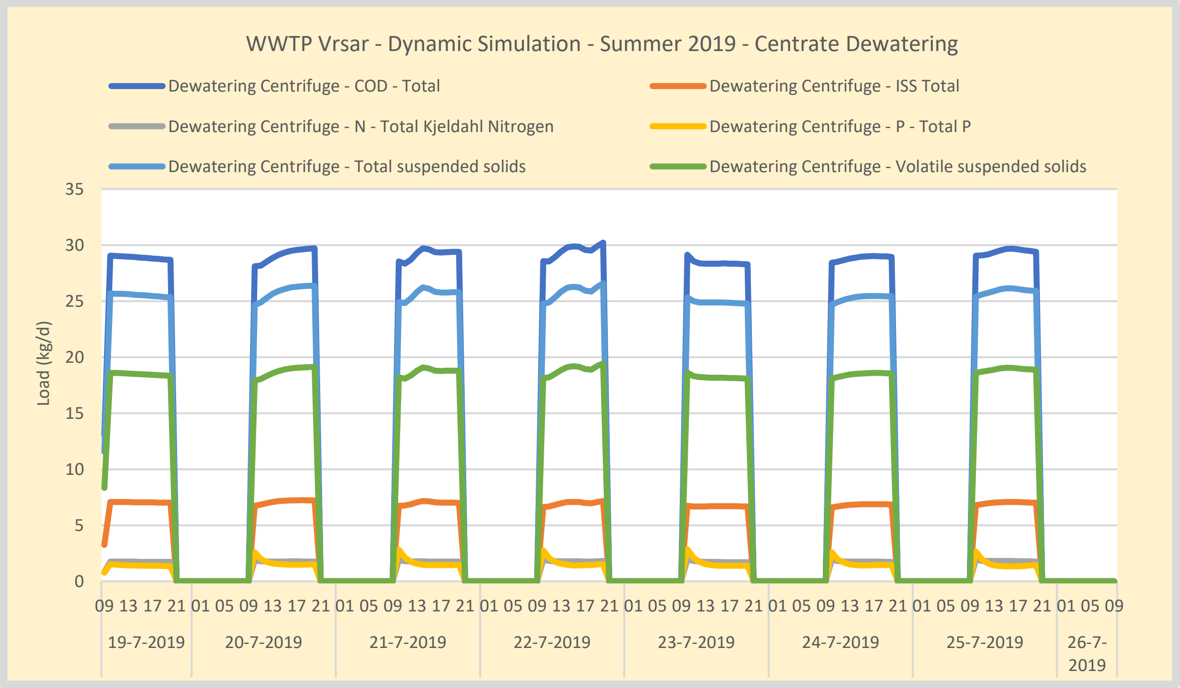


Figure 133. Summer – WWTP Vrsar Centrate load dewatering.

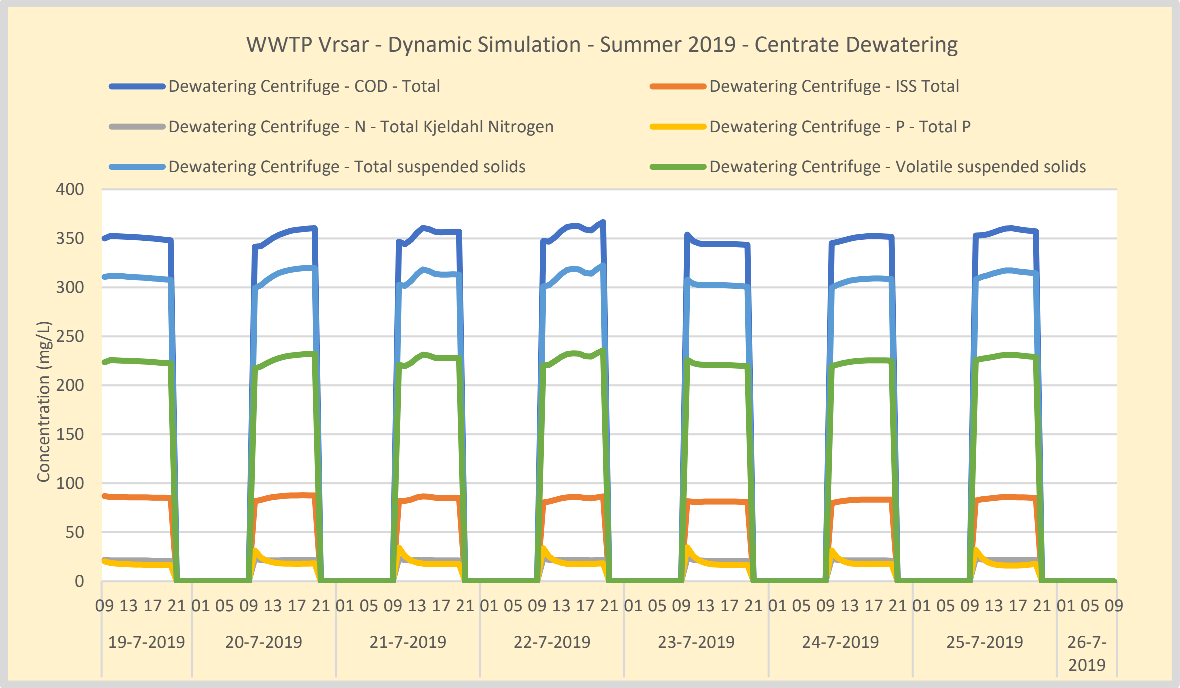


Figure 134. Summer – WWTP Vrsar Centrate concentrations dewatering.

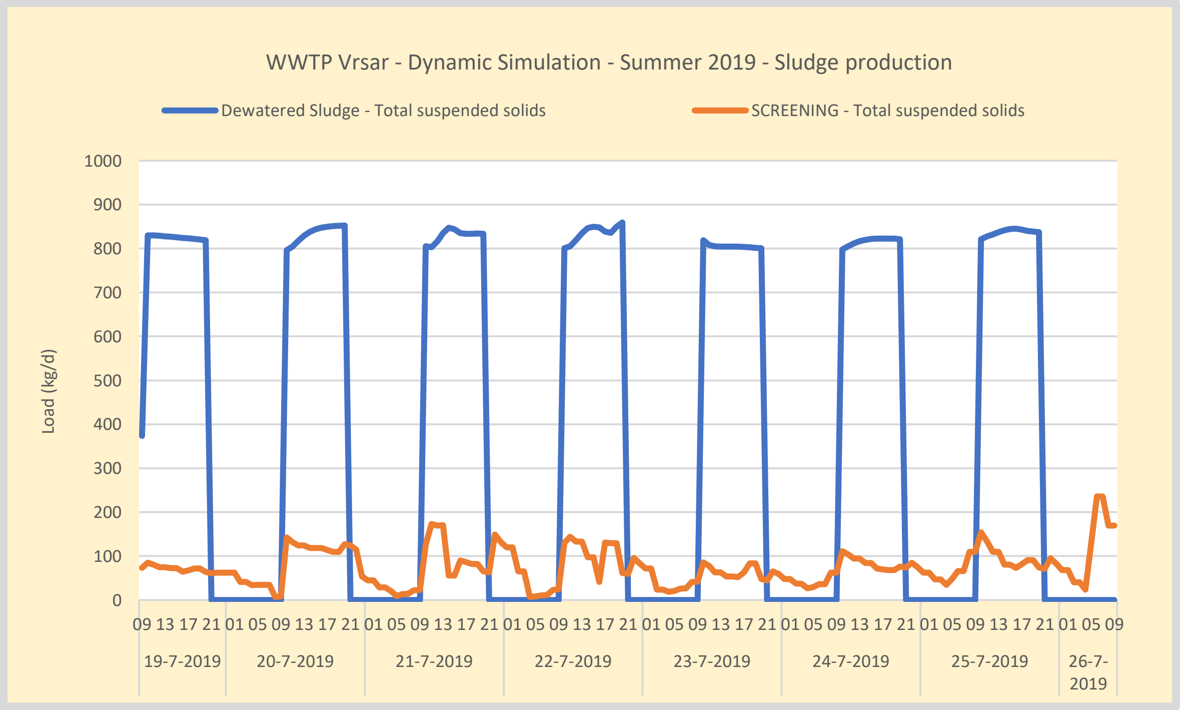


Figure 135. Summer – WWTP Vrsar dewatered sludge load and compacted screening load. Dewatered sludge is operated 10 hours a day at 23%. Screening is produces continuously as a factor of the influent.

8.12 Effluent modelling results

In the figures below the dynamic effluent quality of the plant is presented under summer conditions. No rain events occurred however several peak loadings did take place affecting the simulation results. The measurement is coming from the effluent buffer and has a reduced dynamic profile.

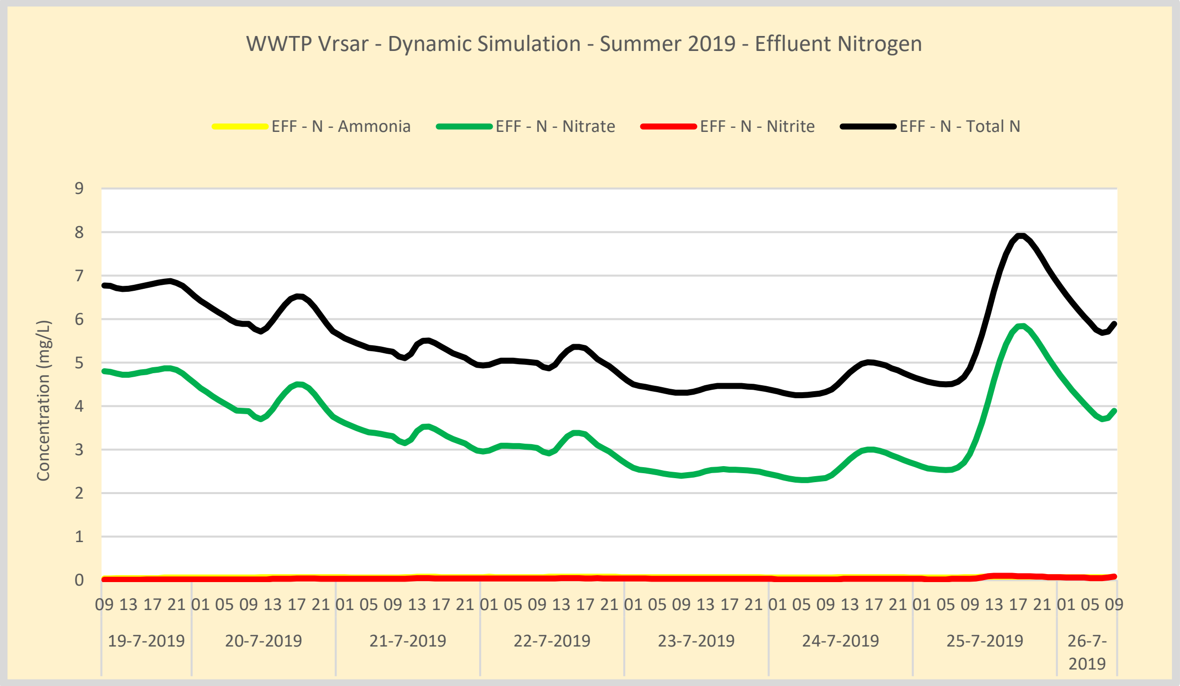


Figure 136. Summer – WWTP Vrsar Effluent nitrogen concentration. Effluent is measured in the outflow of the large effluent buffer. Nitrite production is low and aeration capacity sufficient.

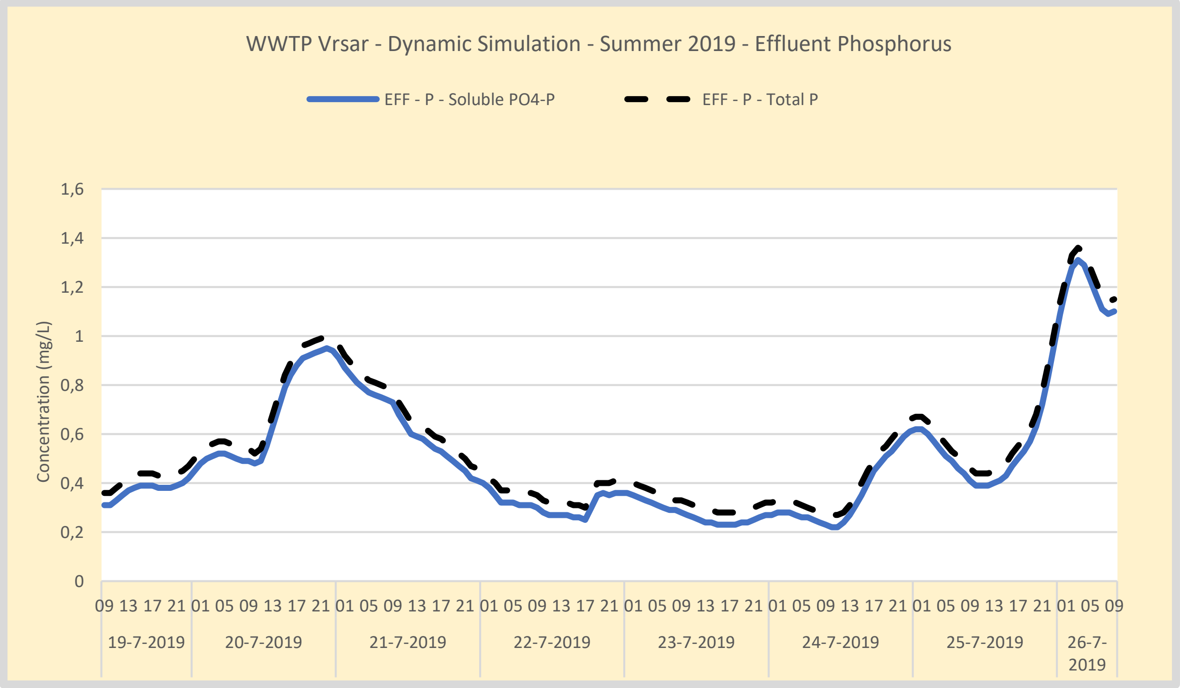


Figure 137. Summer – WWTP Vrsar Effluent phosphorus concentration. No Iron is dosed. Effluent is measured in the outflow of the large effluent buffer.

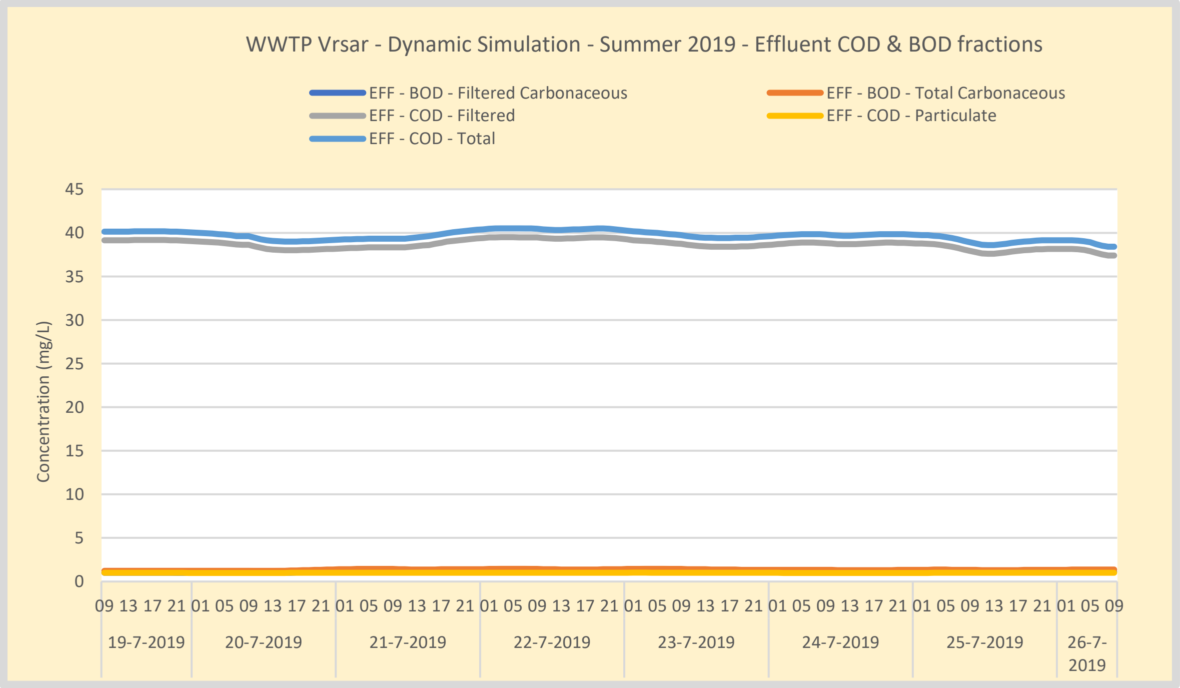


Figure 138. Summer – WWTP Vrsar Effluent COD and BOD concentration. Effluent is measured in the outflow of the large effluent buffer. The Particulate fraction is the result of a MBR efficiency of 99,9% for particulate and 99,99% for colloidal material. Effluent is measured in the outflow of the large effluent buffer.

8.13 Conclusion dynamic simulations summer period 2019

WWTP Vrsar largely operates according to the design based on the 7-day summer influent measurements performed in 2019. The effluent concentration for all parameters is within the projected effluent limits.

The SRT of the plant during summer is not limiting for nitrification. However, the anoxic recycle rate is limiting for the size of the anoxic tank and the optimal NO3 concentration of 2 mgNO3/L cannot be reached. Therefore, it is advised to use maximum internal recycle rates, also during summer low loading conditions.

Phosphorus is removed from the wastewater by Bio-P and without dosage of iron.

The choice of operation is very much determining the plant and effluent results. The selected control strategy for modelling is a simplified strategy however realistic.

The large effluent buffer reduces effluent fluctuations. The trace of solids (0,1%) and colloidal material (0,01%) in the effluent together with the effluent load profiles and flow, can be used for sea water quality modeling in the summer scenario with a fully functional plant.

Summer operation is, compared to winter operation, a classical type of operation within the typical range. Limiting factors during peak loading are the aeration capacity and aerobic SRT which are, according to the dynamic simulations, within the designed range.

The alkalinity of the wastewater potentially can become limiting as the result of low influent alkalinity (this was an estimated value) and stripping of CO2 by high air flows in the aeration tanks and MBR units.

9 Conclusions and recommendations

9.1 General conclusions

- All measurement and modelling data is collected and organized and made available in spreadsheets. The data is processed and effectively presented in this report in figures and graphs from which simulations can be reproduced.
- The detailed design is simulated under realistic dynamic influent and operational conditions. From these results it is concluded that the design meets the effluent requirements.
- For each season it is shown that the treatment plant can treat wastewater to the desired level and has sufficient flexibility to cope with different wastewater conditions.
- The effluent results are determined by the method of operation and the applied process control. This research shows that it is possible to effectively control the plant using simple however realistic process control.
- During summer, all plants remove phosphorus via Bio-P. During the winter Iron may be dosed.
- The effluent discharge can be met under all modelled conditions. This included rain events (during the winter conditions) and several concentration peak loads during both the measurement periods.
- The study shows that the designs have enough operational flexibility to be operated effectively under very different winter and summer conditions.
- Winter operation meets the requirements, however, the required operation not typical in respect to a very high SRT, very long anaerobic and anoxic HRT, very high internal recycle rates proportional to the influent and high DO in the activated sludge system.
- Specific point of attention for (winter) operation are:
    - Application of hydraulic and sludge residence time that are very long.
    - CO2 stripping in the aeration and MBR caused by over aeration, a drop in alkalinity and potentially the pH.
    - Too low internal recycles causing long anaerobic zones and increased decay of biomass, degeneration of nitrification capacity and degraded Bio-P.
    - P-release in the WAS storage tank with HRT more than 2-3 hours.
    - Too little WAS sludge production (long SRT) to meet the Bio-P requirement.
- Summer operation is a classical type of operation within the typical operational range. Dynamic simulations indicate that under summer peak loading the aeration capacity and aerobic SRT can become limiting. On average however, all is within the designed range.
- The dynamic simulation study is successfully completed, and the results can be used for further development of the scenario study and sea water quality modelling.

9.2 Main recommendation

It is recommended to proceed with further development of the scenario analysis and sea water modelling taking in account the presented conclusions.