YRKESHÖGSKOLAN NOVIA

The effectiveness of the wastewater treatment plant in Västankvarn when processing slaughterhouse and normal wastewater

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Abstract

As part of the modernization of the wastewater treatment plant in Västankvarn, the authorities required that the efficiency of the treatment plant in removing nitrogen, phosphorus, suspended solids and BOD was assessed and confirmed. The nearby slaughterhouse causes additional load. By taking wastewater samples and analysing them in the laboratory, it was determined that the wastewater treatment plant successfully treats the wastewater, despite the high load of wastewater from the slaughterhouse.

The work was carried out for 5 months. The results obtained after laboratory analysis allow us to confirm the effectiveness of the treatment facilities. The new treatment plant is able to significantly reduce the load of phosphorus, nitrogen and suspended solids, well below the required thresholds and thereby reducing the nutrient load on the environment.

Language: English
Key Words: wastewater, slaughterhouse, Phosphorus, Nitrogen, wastewater treatment plant

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1 Introduction

The global community has identified the main areas of work for the preservation and restoration of the environment. Sustainable Development Goals (SDGs) provided by United Nations Development Programme is about the 17 goals and objectives that need to be fulfilled by public organizations, governments and companies in order to achieve sustainable development and reduce human impact on the nature. “Clean water and sanitation” - Goal 6 addresses the global communities well-being, economic development, growth, and improved environmental quality. The problem with eutrophication has been identified as one of the main challenges in goal 6. (United Nation, Sustainable Development, 2022)

The eutrophication of the world's oceans is one of the global problems facing humanity. The main cause of anthropogenic eutrophication of rivers, lakes, seas is human activity. There are many types of activities among which various industrial productions, households’ wastewater and agriculture. All this generates wastewater that is directed to the environment.

Wastewater is full of organic waste and chemical compounds that enhance eutrophication. Phosphorus and nitrogen as well as organic substances are the main problems of wastewater. The tasks of treatment efficiency are based on the control of these parameters of wastewater and the results of their purification.

That is why it is extremely important to develop wastewater treatment systems and maintain them at the proper level. Modernization is a way to reduce the negative impact on the environment from human activities. This is a basic element of achieving the goals of SDGs.

1.1 Aim and research questions

The wastewater treatment plant (WWTP) in the village Västankvarn has been upgraded to a more modern one due to the increased load. The load has increased significantly with farms, production facilities, a new slaughterhouse complex and an increase in the number of residents. All this required a new, more productive, and efficient wastewater treatment plant. The modernization required the approval and permission of the local authorities. To obtain a permit, it was necessary to conduct a study of the effectiveness of a new WWTP. To this end, the partners of the project the «Västankvarn Gard Farm», the wastewater treatment systems manufacturer «Raita», the «Sitowize» consulting firm and the «Novia University of Applied Sciences» have joined in partnership to implement this project.

Research and assessment of the impact on water bodies is a part of the modernization of the treatment plant system. The aim of this thesis was therefore to investigate how well the wastewater treatment plant handles the removal of the substances total phosphorus (Ptot), total nitrogen (Ntot), suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium ($NH_4 - N$) during heavy load from the slaughterhouse and normal operation as well.

2 Theoretical background

2.1 The wastewater treatment plant & processes

The old wastewater treatment plant

In 2019, a new slaughterhouse was built in Västankvarn area. Among other things, it was connected to the local sewage water system. In total there are 18 houses, a school, an office building and farm buildings that are connected to the sewage water system. The old rotor waste treatment plant was effective when it was installed up, but nowadays it cannot meet modern requirements. In 2020 it was decided to modernize the WWTP.

According to the monitoring data input load to the treatment plant showed an increasing average rate from 4,7 m3/d in 2007 to 11,6 m3/d in 2019 (Table 1~~Table 1~~).

Table 1. The average input load of the treatment plant in 2007-2014 and 2017– 2019 years.

	2007	2008	2009	2010	2011	2012	2013	2014	2017	2018	2019
Flow rate, m^3/d	4,7	4,0	2,0	3,8	3,6	7,1	7,0	8,8	8,7	8,9	11,6
BOD, kgO2/d	0,46	0,50	0,22	0,78	0,69	3,7	3,5	1,9	7,4	9,6	8,5
AVL = 0,07 kg O2/as*d	7	7	2	11	10	54	50	27	106	137	121
Phosphorus, kg/d	0,049	0,025	0,020	0,040	0,039	0,11	0,11	0,12	0,14	0,12	0,14
Nitrogen kg/d	0,22	0,23	0,11	0,31	0,28	0,50	0,64	0,58	0,50	0,81	0,94

Studying the data of previous years, it can be seen that the volume of inflow has increased significantly since the beginning of observations, and especially in 2017. This is due to the development of the area, the construction of new production and other premises, an increase in the number of residents in the village.

Obviously, with the increase in the inflow of wastewater, the efficiency of the old treatment system decreased. This is clearly seen by the values of BOD and other parameters in the table.

2.2 Description of the new wastewater treatment plant

In this chapter the system of the treatment plant and function of the different parts of the plant will be described.

«Raita PA XL 30 Biochem MA» has been selected as a treatment plant. The system was developed and produced by Finnish company «Raita Environment Oy». This is a modern smart system that has a remote control. According to the data provided by the producer the treatment plant fits the requirements of European Union regulation and European standard (EN 12566-3:2005). (Oy Raita Environment Ltd, 2021)

The carrying capacity of «Raita PA XL 30 Biochem MA» treatment plant is 30 m3/24 h. That means it covers all needs of the village and farm. The system has an extra capacity in case of needs will grow in the future.

Since the WWTP of Västankvarn village was renovated, the new system was installed in the old one. Some parts of the old system continue to participate in the processing of treatment (Figure 1Figure 1)

The sewage system consists of pumping wells and inspection wells connected by pipes. Large buildings, households and farm production facilities are connected by pipes with a diameter of 110 mm. Slaughterhouse as well as small and remote buildings are connected by pipes of smaller diameter - 50mm.

The slaughterhouse has its own pumping well for channelling sewage into the general sewage system of the village of Västankvarn. In addition, special grease traps are installed to prevent the ingress of fat residues into the sewage system. The cooled fat accumulates on the walls of pipes and blocks the movement of sewage.

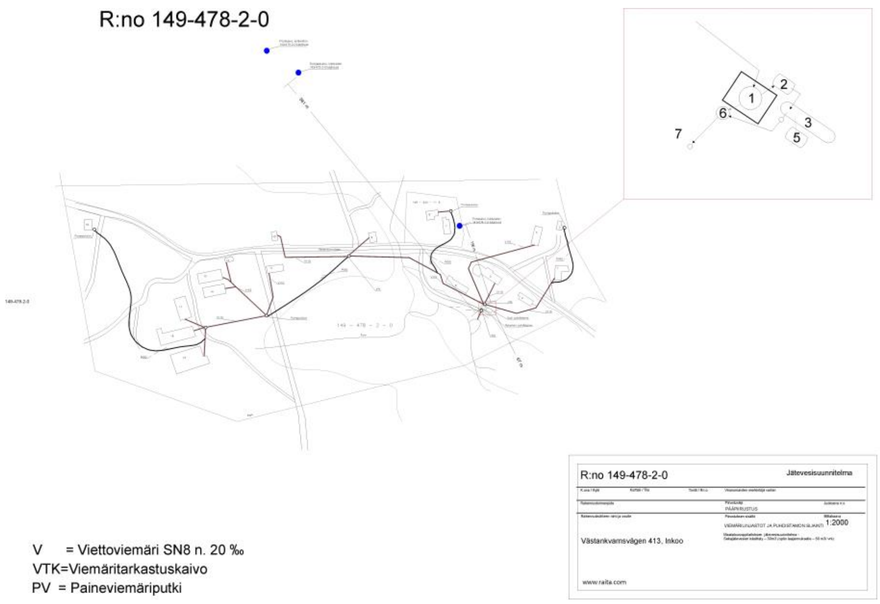

Figure 1. The plan of the sewer system in Västankvarn

The system of the treatment plant consists of 7 tanks (Figure 2~~Figure 2~~). Each tank plays a role in the bio-chemical treatment process.

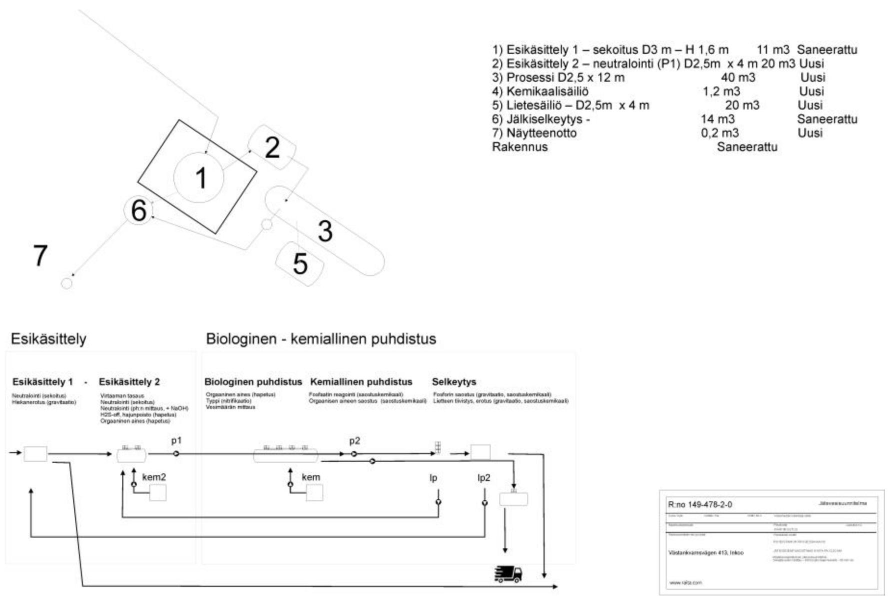

Figure 2 Tanks of the treatment plant

There are:

Preliminary tank – a concrete tank from the old system, the Tank 1. The main task is to collect a wastewater and protect system of overflow. (Parameters: D 3 m – H 1,6 m, vol. 11 m^3) (Figure 1Figure1).

Mixing and neutralization tank – the part of a new system, the Tank 2. The main tasks are to aerate wastewater and dissolved organic matter; phosphorus neutralization by adding chemicals. (Parameters: D 2,5 m x 4 m, vol. 20 m^3) (Figure 1Figure 1)

Tank 3. Process tank – the part of a new system. The main tasks are continuation of aeration, nitrogen nitrification, clarification. (Parameters: D 2,5 m x 12 m, vol. 40 m^3) (Figure 1Figure1).

Tank 5. Sludge tank – the part of a new system. A sludge is removed from the process tank and collected for the next transportation to a municipal WWTP or a composter. (Parameters: D 2,5 m x 4 m, vol. 20 m^3) (Figure 1Figure1).

Well LP. A pump is installed into the well, which removes sludge residues from the pipes before emptying the process tank 3. After removing the sludge, this pump pumps out the treated water. Then it releases tank 3 for a new portion of untreated water (Figure 1Figure1).

Tank 6. Sedimentation/secondary settlement tank – second concrete tank of the old system. The main task is extra sedimentation. (Parameters Volume -14 m^3) (Figure 1Figure1).

Tank 7. Sampling point tank – the part of a new system. The main purpose of the tank is to release treated water, to sample and observe the processing of emptying the system (Figure 1Figure1).

Smart control system. It allows controlling the system remotely via the connection to the network. It controls pH-parameters, the volume of the flow and adding of the chemicals. The system is programmed to start the different kinds of treatment processing.

The Biocom XL system was implemented considering the existence of the previous system, which on the one hand makes it possible to significantly save resources on dismantling and recycling the old rotary system. On the other hand, it makes it possible to increase the efficiency of processing the incoming sewage stream. The system is set up for 12 hours cycle. It means that each 12 hours the portion of wastewater that was taken and treated will be released.

2.3 Water treatment processes

The process starts immediately when wastewater comes to the first tank by mixing, aeration and oxidization. At the same time controlling measurements continue to collect data for Smart control system. Measurements of pH and volume of wastewater are the parameters that help Smart control system program to choose the right amount of chemicals.

As the wastewater flow is not homogenous the different amounts, conditions and contaminants come with the wastewater to the treatment plant. Obviously, the conditions of the wastewater are changing fast during the day. During working hours business facilities produce specific waste depending on the business processes. In morning and evening sewage system is mostly loaded with typical wastewater from the living houses.

In general, the process is divided into a few main steps:

-Decomposition and grinding organics and suspended solids (SS)

-Microorganisms (mostly bacteria) break-down organic compounds

-Chemical treatment and neutralization

-Biological treatment process and secondary clarifier

-Residual sludge is removed for further processing on the municipal WWTP

These stages are implemented into the cycle of operation of the treatment plant used in Västankvarn.

2.3.1 Biological Wastewater Treatment Process

Once wastewater reaches the treatment plant the process of treating starts. The primary step is the biological wastewater treatment process. When enough wastewater accumulates in the preliminary tank, the pump starts working and transfers the content of tank 1 into tank 2. Here the aeration of the organic material in the wastewater begins. When activated sludge from the process tank 3 is mixed with the pre-treated wastewater in tank 2 and in presence of oxygen the nitrification of ammonia starts. Dissolved oxygen is supplied with the aeration into the wastewater which is needed for the aerobic biological organisms to break down organic material (Jain & Singh, 2022). Microorganisms consume organic material and oxygen. The result of their consumption is active sludge.

Nitrification and denitrification are taking place in tank 3. Untreated domestic wastewater is rich in ammonia (NH_3). (Keffala, Galleguillos, & Ghrabi, 2011, ss. 389-399) Nitrification is an aerobic microbial process that converts ammonia (NH_3) to nitrite ($N0_2$) and after that to nitrate (NO_3).

Aerobic stage

Nitrosomonas bacteria

$$NH_3 + O_2 \rightarrow N0_2\text{-} + H$$

Nitrobacter bacteria

$$N0_2\text{-} + H_2O \rightarrow NO_3\text{-} + H$$

Denitrification is an anoxic microbial process that is degradating nitrate (NO_3) to nitrogen gas (*N*)

Anoxic stage

Heterotrophic bacteria

$$NO_3\text{-} + C \text{ (organic carbon)} + H\text{+} \rightarrow N_2 + H_2O$$

These processes require different conditions: the first takes place with aeration, which means the addition of oxygen to wastewater, and the second - without oxygen saturation. During the clarification stage denitrification occurs.

The incoming air at the aeration stage also removes the released nitrogen from the atmosphere through ventilation ducts on the top of tank 3.

These two processes play an important role in the wastewater treatment process. In fact, they repeat the same processes that occur in the global nitrogen cycle in the natural environment. Denitrification and nitrification in nature are part of the global passage of the nitrogen cycle Figure 3~~Figure 3~~.

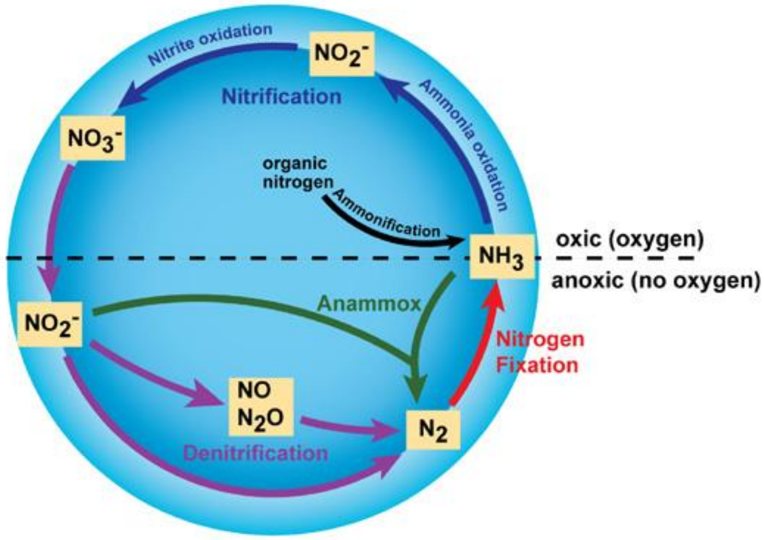

Figure 3 Major transformations in the nitrogen cycle (Bernhard, 2010)

2.3.2 Chemical Wastewater Treatment Process

The WWTP faces an equally important task of removing phosphorus. These phosphorus pollutants also have a serious negative effect and increase the eutrophication of the world's oceans if they enter the natural environment.

The chemical process helps to carry out the chemical deposition of phosphorus. Phosphorus is removed by adding the "RAKE iron chemical" a product by Raita Environment OY. It is added at the beginning of the aeration and purification process to tank 2. The reacting iron sulphate and phosphorus precipitate at the bottom of the tankand is later removed with the activated sludge. (Gheirghe, Marius-Daniel, Giurca, & Calin, 1989)

$$Fe_3{+}{+}H_n(PO_4)n - 3 \leftrightarrow FePO_4 + nH$$

The process starts while the aeration is going on in tank 2. "RAKE iron chemical" is dosed into tank 2 and reacts with phosphorus. After the ending of the aeration in tank 3, a clarification period begins. During the clarification activated sludge and phosphorus precipitate to the bottom of the process tank. Then it is removed by the bottom pump with activated sludge to tank 5. After several cycles when tank 5 is full of activated sludge it is removed from the tank and delivered to the municipal water treatment plant for further treatment.

In this way, phosphorus is removed from wastewater. This prevents phosphorus from entering the environment. The anthropogenic load on the local water system is reduced, eutrophication is prevented.

2.3.3 Clarification

Clarification is the last stage of the process. After the aeration is stopped, the process of clarification begins. Water sedimentation and gravity contribute to the deposition and removal of suspended solids. Activated sludge flakes sink under the influence of gravity and precipitation. Thus, clarified and treated water is ready to be discharged.

By stopping aeration, the lack of oxygen starts the denitrification process and helps to break down nitrate (NO_3) to nitrogen gas (N_2). At the end of clarification, the treated water is pumped out of the treatment plant by a pump. The treated water is pumped through pipes, and a small portion enters a separate control tank during pumping, where the efficiency of the treatment plant can be easily checked.

The treated water is discharged directly into the nearest water stream.

2.4 Legislation

As described earlier, it is necessary to use thresholds when evaluating the effectiveness of the cleaning process. According to the legislation, an effective wastewater treatment system should not reach or exceed the threshold values. Local authorities have issued thresholds requirements for treated wastewater.

In the decree “Government decree treatment of domestic waste water in areas outside sewerage networks 157/2017” (Ministry of the Environment, 2017) the following thresholds are set for a number of indicators (Table 2~~Table 2~~).

Table 2. Thresholds values

Thresholds	Concentration legislation, mg/l	Value	*Minimum power, %*
Total Nitrogen, Ntot	-	mg/l	40%
Total Phosphorus, Ptot	0,7	mg/l	85
Biochemical oxygen demand, BOD7	30	mgO_2/l	90
COD	125	mgO_2/l	75
Suspended Solid	35	mg/l	
Ammonium	maximum nitrification rate		

*- The first number is the data of the authorities, through the slash data of legislation.

These thresholds should not be exceeded when wastewater is treated with an effective wastewater treatment system.

On the other hand, the local authorities have established stricter requirements for threshold values for BOD, phosphorus and ammonium. The data is presented in the table (Table 2Table 3).

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Table 3. Thresholds set by local authorities in the decision

Parameter	Concentration, mg/l	Minimum power, %
Biochemical oxygen demand, BOD7	≤ 15	≥ 90
Phosphorus, P	≤ 1,0	≥ 90
Nitrogen	-	-
Ammonium	maximum nitrification rate	

Comparing the data from decree “Government decree treatment of domestic waste water in areas outside sewerage networks 157/2017” and the decisions of the local authorities, in study will be used the values with the most stringent requirements.

According to the calculated concentrations of the parameters provided by the Association of Finnish Water Utilities in their guide ”Finnish Industrial Wastewater” (Finnish Water Utilities Association, 2018) The data were accumulated and analysed by the Association (Table 44Table 4).

Slaughterhouses are included in the industrial facility, so these standards could be used for evaluation the wastewater from slaughtering.

Table 44. Concentrations of wastewater received in Finnish WWTPs

Parameter	Unit	Fluctuation range	Median	n
Suspended Solids	mg/l	190–438	349	13
Total Nitrogen	mg/l	48–74	65	13
BOD	mg/l	199–333	272	13
Total Phosphorus	mg/l	8.1–13	10	13
COD	mg/l	483–805	596	10

These values are not mandatory thresholds or standards; however, they can serve as additional indicators for understanding, comparing, and evaluating wastewater generation in the studied case on Västankvarn.

3 Methods

3.1 Study site

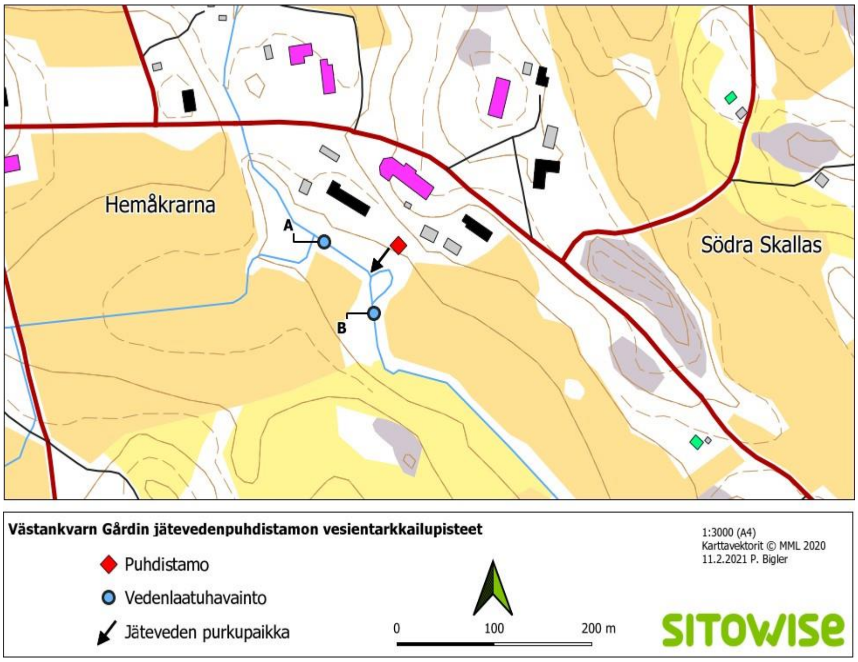

Figure 4 WWTP Location

Västankvarn is a small village located in Inkoo municipality, Uusimaa region, Finland. Västankvarn Gård is an experimental, training farm for the bioeconomy degree programmes at the University of Applied Sciences Novia. The farm's business, in addition to experimental activities and training, includes agriculture with milk production, forestry, agricultural tourism, dog training camp and property leasing. (Västankvarn Gård, 2016). 33 people are living in Västankvarn and 35 are on the working facilities during the workdays. Västankvarn is located near the coastal zone of the Gulf of Finland of the Baltic Sea.

3.1.1 Normal and Slaughter Day

Normal and Slaughter Day

The authorities in the construction permit put forward their own requirements for conducting research. It was indicated which parameters that should be analysed and it was proposed to carry out sampling and analysis in two variants. The first option on the days of slaughtering at the slaughterhouse - called from here on Slaughter Day (SD). The second, on the days when slaughtering, was not carried out - called from here on Normal Day (ND).

An additional requirement was the need to take samples from the nearby stream, upstream to the place of discharge of treated water and downstream. This is necessary to be able to assess the impact of the treated water on the natural state of the stream.

The design of sampling was thus divided into two main parts. Samples to be taken on ND and on SD.

On each sampling day, samples were to be taken from the wastewater stream immediately before entering the pre-treatment tank. Twelve hours after the end of cleaning, when the system released treated water at the outlet. At the same time, samples were to be taken from the stream on the days of slaughter.

The requirement of the authorities indicated the need to conduct at least 4 rounds of sampling during 4 months. Based on this, I planned my research using the Gantt chart. Within 5 months from the moment of the test launch, I was supposed to carry out all the sampling. There was no strict requirement for the order of sampling.

The main slaughtering days are Monday, Tuesday and Wednesday. The difficulty was that the slaughterhouse had a work plan for slaughtering cattle for a couple of weeks ahead. Long-term planning of sample collection dates was not possible.

Another problem of planning was how to take samples. First, samples of ND and then SD or vice versa.

An important question to answer was: how long the water is in the process of purification? Obviously, wastewater from SD is containing more organic substances such as blood and other biological fluids of animals, as well as particles of fat, turf, earth, and other components associated with the slaughter process.

Simply, the wastewater in SD would be more saturated with pollutants than in ND. And this requires more time for cleaning and means that there may be residues of pollutants in the ND samples received on SD.

That is, there was a possibility that the water that got into the system during the SD could remain in the tanks of the treatment plant. And even a few days after the end of the SD water inflow, there was a high probability of obtaining uncorrected data when sampling the release of treated water into nature. To do this, the sampling was planned so that samples on ND were collected before SD.

The operation cycle of the multifunctional control system of the treatment plant is 12 hours. Day and night cycle. This was said earlier. Based on this, it was planned that the water received during the daytime is released after about 12 hours. The release of treated water takes place from 13.00 during the day and at 01.00 at night. Based on this, it is assumed that the incoming wastewater during the working day and in the evening will be displaced with residues from past cycles. After purification, stagnation, and clarification, the water discharges at the end of the cycle. The next cycle starts at 02.00 am.

Thus, the following picture of the study design emerges. Samples were to be taken once a month for 4 months. Sampling once a month during ND, and once a month during SD. (Table 55Table 5).

Table 55. Sampling scheme by Normal Day and Slaughter Day

	Normal Day, ND	Slaughter Day, SD
Income wastewater	4 times	4 times
Outcome treated water	4 times	4 times
Upstream sample		4 times
Downstream sample		4 times

3.1.2 Sampling plan

“A Normal Day”

At first, samples of incoming wastewater were taken.

The beginning of the water treatment cycle. It was taken from the falling stream into tank 1.

Since the flow can vary depending on the source (residential building, school, office, kitchen), we planned to take the sample in small portions of 5 repetitions with an interval of 5-10 minutes. The sample volume was 3 liters. In the process of sampling, the PH and temperature were measured by the device. All the collected data was recorded.

Secondly, samples of treated wastewater were taken.

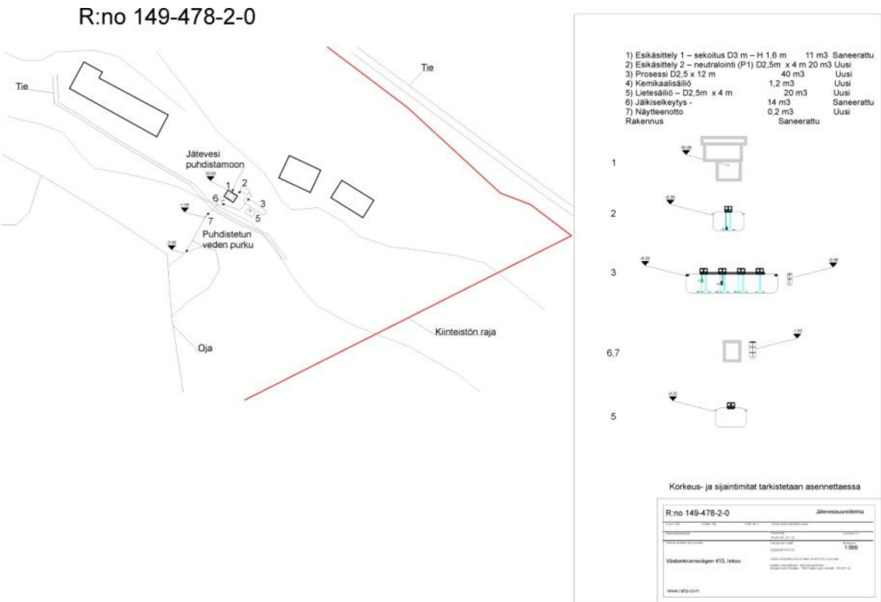

Figure 5 Location and tanks of the treatment plant

The end of the water purification cycle. It was taken from the falling stream into tank 3 (Figure 5Figure 5).

Since the flow of treated water coming from tank 3 is relatively stable we planned to take a sample in small portions of 5 repetitions with an interval of 5 minutes. The sample volume was 3 litres. During sampling, the pH and temperature were measured and recorded.

Samples from the stream upstream and downstream from the point of discharge of treated water were taken. The samples collected at the beginning and at the end of the cleaning cycle, as well as from the stream, were stored in a cool black box and are delivered to the LUVI laboratory on the next working day in the morning.

“A Slaughter Day”

- Sample of incoming wastewater.

- Sample of the outgoing treated water.

- Sample from the stream upstream.

- Sample from the stream downstream.

The sample from the stream upstream was taken by immersion of a sample bottle with a volume of 1 litter. The sample was taken in small portions of 5 repetitions with an interval of 5-10 minutes. As instructed in the requirements by the authorities, a sample was taken separately in a sterile bottle to measure the number of *Escherichia coli* bacteria. And also, a sample was taken for the analysis of dissolved oxygen. See 3.3.13. In the process of sampling, the pH and temperature were measured and recorded.

3.1.3 Samples from the nearby stream

Treated water from a WWTPs is usually directed to a nearby pond and drained or into a river, stream, ditch, a lake system, or the sea. The pipe should discharge the treated water into the stream so that the transfer and subsequent integration of residues and water into the global cycle can take place.

In Västankvarn, next to the WWTP, there is a small stream with a width of 2.5 – 3 metres to 1.5 metres in the dry season. According own observations, the water in it moves with considerable speed, it is not stagnant water.

The drainage pipe does not lead the treated water directly into the stream. A wetland is formed artificially or naturally at the place where the pipe is located. A small branch 5-7 metres wide forms a small island. On one side a stream flows, on the other side there is a wetland 20-30 metres long. This wetland is a kind of additional natural barrier, able to collect the pollutants that have not been removed due to treatment or have been absorbed in case of system failure or overflow.

According to the authorities, it is necessary to take samples upstream and downstream from the discharge point. Samples should only be taken on the days of slaughter.

In addition to analysing the same parameters that are analysed at the wastewater treatment plant, we also took water samples for E. coli. And dissolved oxygen.

During the development of the study project, it was decided that the samples would be taken upstream after the inflow to the treatment plants had been sampled. The downstream samples would be taken at the time of sampling when the treated water was discharged.

In general, the process was as follows: Collection of a water sample in a container for delivery to the laboratory. Two types of containers. Sterile containers for the Escherichia coli test and the usual sampling in a clean container for analysis. Measurements with the pH and temperature metre. Taking a separate special sample to determine the dissolved oxygen content. Sewage flow speed

Before sampling, the flow rate in the sewage system had to be measured. This was to determine how long it takes for the slaughterhouse's wastewater to reach the treatment plant.
Knowing how long the wastewater takes to travel can help determine exactly when the water contaminated with slaughterhouse waste enters the treatment plant. So, water samples can be taken when the slaughterhouse waste is contained there. This was also a requirement of the authorities in the decision.

The test was carried out on 28.06.2021. The weather temperature was +27, sunny, no rain. The test site was in the slaughterhouse car park near a slaughterhouse building in the wastewater well. The task – to determine the flow rate of the wastewater system. A biodegradable fluorescein sodium salt dye was used to clearly identify the slaughterhouse wastewater. This dye was chosen because its fluorescence properties are known at concentrations of 0.01% to 0.000001%. (Williams, 2003) Such a range makes it possible to produce a highly visible indicator with a small amount of the substance.

It is a dark red powder (Figure 5), that dissolves in water and produces different colour combinations depending on the concentration. From a dark red solution at high concentration to a bright green colour with a fluorescent tint. It is used as an indicator dye that looks from yellow-green to light green depending on the acidity of the solution and concentration.

Figure 6 Fluorescein sodium salt – a dark red powder

The difficulty was to add enough powder to the wastewater so that the concentration of the indicator in the water could be seen for observation. If too little is added compared to the amount of wastewater added, the result is difficult to observe. Adding too much can damage the wastewater system as well as the treatment plant itself and the environment.

Too high a concentration can result in a dark red colour that is difficult to see in the wastewater system.

Experimentally, it was decided to dilute the powder to a level of 15000ppm per 1 litre. If we assume that 4-5 m3 of wastewater is delivered on the day of slaughter, the calculations look like this:

5m3 – 5000 litres, is an average amount of wastewater per day, 1 ppm – part per million (1 g / 1 000 000 g = 0.001 g / 1 000 g = 0.001 g / 1 L).

15g of the fluorescein sodium salt + 1L of water = 15,000ppm 15 g / mass of 5 000 000 g = 3 ppm = 0.0003%.

This concentration is in the order of 0.01% to 0.00001%. This means that we will get a strongly fluorescent colour.

Figure 7. Fluorescein sodium solution

The solution was added to the pump well of the slaughterhouse at 15:25:28 Helsinki time. The red frame in Figure 8Figure 8, shows the date and time when the picture was made.

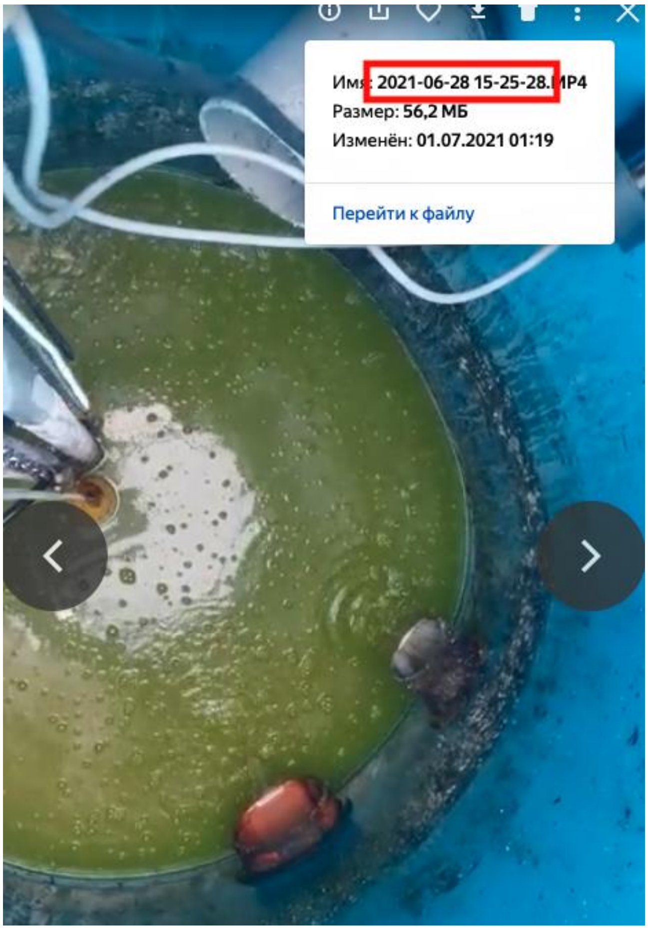

Figure 8. The photo was made after the colour compound was added.

As can be seen in Figure 8~~Figure 8~~, the concentration of the dye in the sewer well clearly reveals the indicator.

At 15:29, the pump started in the slaughterhouse well. After about 55 minutes, at 16:24, the coloured water was noticed in the input well before the station. I used a Canon EOS 80D camera to film the inflow, and according to the camera's timing, the colour compound appears between 16.23.50 – 16.24.10. In the last two pictures the water became distinctly greenish.

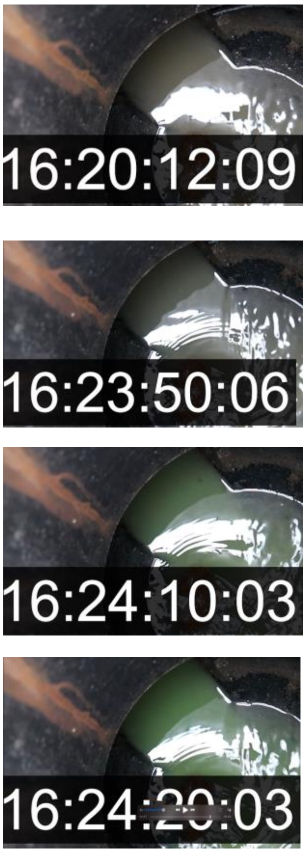

Figure 9. From normal colour of wastewater to greenish water in the system

Once pumping begins, coloured wastewater enters the system and reaches the input well and treatment plant after 55 minutes.

It is important to pay attention to the colour of the water before it takes on a greenish tint. A greyish tint is a colour that usually occurs on days when there is no discharge from the slaughterhouse.

With the result of 55 minutes, it can be determined with certainty when the wastewater enters the treatment plant.

3.2 Sampling

This section describes in detail how the sampling took place.

The test was carried out 29.06.2021 at 16.30. The weather temperature was +27, sunny, no rains. Test place was in WWTP building near input fall into the pre-treatment tank 1. The task – taking the SD input samples.

Sampling on the day of slaughter. According to the sampling plan, we started taking samples. After slaughter, the slaughterhouse workers wash their workplaces. The starting time for cleaning and sanitising the premises depends on the workload. As a rule, the largest amount of wastewater is produced after 3 pm. We know that the water from the slaughterhouse reaches the treatment plants within 55 minutes. We have planned to start sampling at 4-5 pm.

The system of the treatment plant works in a 12-hour cycle. After 10 hours of the cycle, the lightening process started. Every day and night at 3pm and 3am the system starts a new cycle. This means that the water from the slaughterhouse arrives at the beginning of the cycle.

Figure 10. Reddish wastewater from the input fall

Due to the now known water velocity in the system – 55 minutes – samples were taken from 16:30. The water colour was reddish, indicating the source of the wastewater (Figure 9~~Figure 9~~).

Since the water entering the treatment plants from the sewage system can have different compositions (not homogeneous), it was decided to collect small samples in a container, with breaks of 5-10 minutes, depending on the strength of the flow and its type. There are two types – wastewater that enters the treatment plants and treated water after purification.

After accumulation in a container with sufficient volume, a sample is taken for laboratory analysis. A total of 5 replicates were carried out with one set of wastewaters for sampling. During sampling, the temperature and pH were measured with a pH-metre. (Figure 11~~Figure 11~~, Figure 12~~Figure 12~~, Figure 13~~Figure 13~~)

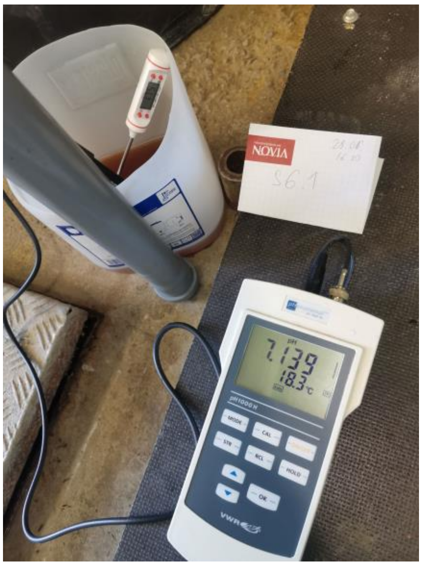

Figure 11. Sample 6 repetition 1 time 16.30. pH 7,139, temperature 18,3C

Figure 12. Sample 6 repetition 3 time 16.50. pH 7.053, temperature 18,1C

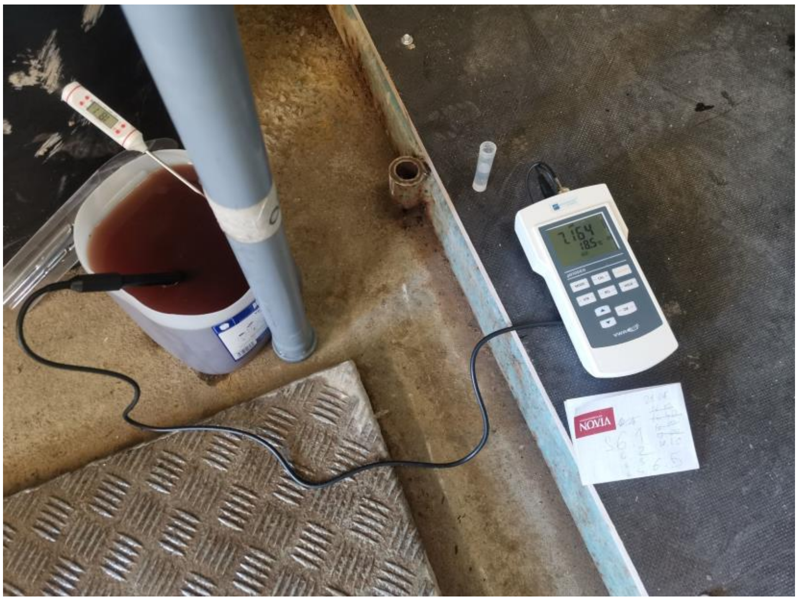

Figure 13. Sample 6 repetition 5 time 17.10. pH 7.164, temperature 18,5C

It is noted that the amount of wastewater in the container has increased. A full container holds about 3 litres. When a full container has been collected, its contents are bottled for samples. The bottles were delivered to LUVY. The bottles were labelled with:

- Date,
- Time,
- Place of sampling
- flow type
- research parameters.

Finally, all sampling devices were washed with plenty of fresh water. The pH metre was cleaned with distilled water. Regardless, it should be noted that there were no special sample volume requirements for the LUVY lab. With one exception: to determine the solid particles in the treated water at the outlet of the treatment plants, a larger sample volume is required. This is because the water is cleaner and a larger sample volume is needed to determine the presence of solids.

The test was carried out 29.06.2021 at 17.30. The weather temperature was +27, sunny, no rains. Test place was near WWTP upstream of the water stream. The task – taking of environmental samplings.

Sampling from the water stream. The sampling site is 25 metres upstream from the wastewater discharge point. The location was determined based on the recommendations of the "Sitowise" map (Figure 4Figure 4). However, it was not strictly determined. Rather, it is important that the gradient and flow of the watercourse allow you to take a sample without disturbing the natural course of the water flow, without lifting the suspension and silt from the bottom.

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Figure 14 Sample 11 time 17.30, pH 6.884, temperature 20,8C

There were two parameters that had to be carried out by special methods. The oxygen content and the degree of saturation are collected in special vessels without access to air. In order to perform the measurements in the laboratory, reagents had to be added on site. I have described the Winkler method in detail in section 3.3.13. The container with the precipitated reagent is stored in a dark, cool place and later delivered to the LUVY laboratory.

Figure 15 Bottles with reaction flakes

Figure 16 Water temperature in the water stream 19,3C

During the sampling, a problem was found related to the schedule of the laboratory and the time of sampling. The water from the slaughterhouse was delivered to the treatment plant at 17.00, the laboratory could no longer accept late samples at this time due to its work schedule. We had to leave the samples for storage in a dark, cool place until the next working day and deliver them to the laboratory in the morning.

The test was carried out during the night 30.06.2021 at 01.30. The weather temperature was +19, clear sky, no rain. Test place was Output well tank 7. The task – taking output samples.

As mentioned earlier, the treatment plant has a 12-hour cycle. This means that tests have to be carried out at night. Wastewater that arrives from 15:00 onwards goes through the stages of purification, aeration and clarification, and some of it is only released after 12 hours. Since the system does not completely empty septic tank 3, some of the incoming water will definitely remain in the system. While it is not possible to track the total amount of sample received at the time the first part of the sample (sample of incoming wastewater 6) is taken, it is planned to assume that this water will be treated and leave the system after 12 hours. After starting pump 2 and flushing out any sediment that may have entered the pipes from the previous cycle with clean water, sampling began at the outlet well. Preparation for sampling (Figure 17Figure 17).

Figure 17. Place of sampling

As with the SD samples of the inflowing stream, samples of the outflowing stream are also taken in small portions in 5 replicate s. This is planned in order to obtain samples that cover the entire volume of treated water as accurately as possible.

However, due to the limited operating time of the pump, the intervals started at 5 minutes. pH and temperature measurements were taken. After the 5th repetition, the water from the bucket enters the bottles with the samples (Figure 18Figure 18).

Figure 18. Sample 9 repetition 2 time 1.30, pH 5,989, temperature 18,6C

The next morning, the samples are delivered to the laboratory.

The test was carried out during the night 30.06.2021 at 02.30. The weather temperature was +19, clear sky, no rain. Test place was on the water stream downstream. The task – taking environmental samples.

At the end of this long day, after sampling, samples are taken from a water stream 25 metres downstream from the wastewater discharge point. Again, pre-cleaned equipment is used. Container and instrument for pH measurement.

Figure 19. Sample 14 time 2.19, pH 6,804, temperature 19,4C

Finally, all samples collected on the afternoon of 29.06.2021 and the morning of 30.06.2021 were delivered to the LUVY laboratories in the morning.

This sampling method was repeated in all subsequent iterations.

3.3 Observation parameters

The research design was based on the Regional state administrative agency's decision N 151/2021. In this decision a list of parameters that need to be studied was specified and adopted. This list has become a foundation for collecting materials for subsequent analysis in the LUVY laboratory.

The data is presented in the table for ND and for SD. Since threshold values are not defined at the legislative level for all parameters that are studied in the work, it makes sense to highlight only those parameters that have threshold values. To do this, threshold values have been added to the tables with parameters (Table 66~~Table 6~~).

Table 66. Studied parameters and threshold values

Analysis of samples	Input	Output	Thresholds, mg/l
Suspended Solid	x	x	35
Alkalinity	x	x	
Total Phosphorus P_{tot}	x	x	*≤ 1,0*
Total Soluble Phosphorus	x	x	
Chemical Oxygen Demand COD	x	x	
Biochemical oxygen demand BOD	x	x	*≤ 15*
Total Nitrogen N_{tot}	x	x	15
Ammonium NH_4-N	x	x	Max. rate
Sum nitrate & nitrite nitrogen	x	x	
pH	x	x	
Electrical conductivity	x	x	
Soluble precipitation metal (Fe / Al)		x	

3.3.1 Suspended Solids

Solids are common in wastewater. It contains pathogens (microorganisms), solids, and nutrients. In addition, there are various chemical elements such as nitrogen phosphorus, solids, chemicals and other hazardous materials. The suspended solids give an understanding of the amount of organic and inorganic solids in a sample. By observing and controlling the solids content, it is possible to detect changes in the operation of the wastewater treatment plant. (Theobald, 2013)

LUVY laboratory uses the method for determination of solids in samples named SFS-EN 872:2005 (TL64). This European Standard describes a method of determination of suspended solids in raw water, wastewater and sewage by filtration through glass fibre filtres. (SFS-EN 872:en, 2005). There is no upper limit for the estimation, but the lower limit according to the standard is 2 mg/l.

3.3.2 Alkalinity

The ability of water to deacidify or absorb hydrogen ions is called alkalinity. This is the sum of all acid-neutralizing bases in water. (n.d., The Role of Alkalinity in Aerobic Wastewater Treatment Plants: Magnesium Hydroxide vs. Caustic Soda, 2015) It is one of the ways to measure the readiness of the wastewater treatment plant for effective treatment. Among other things the process of biological wastewater treatment produces hydrogen ions. Alkalinity is necessary for the treatment process to maintain the pH of the solution at the required range. When alkalinity decreases, hydrogen ions are not removed, resulting in a drop in pH, and the wastewater treatment process slows or even stops. (n.d., The importance of alkalinity in wastewater treatment, 2018)

LUVY laboratory uses SFS-EN ISO 9963-1(TL64) - the method of titrimetric determination of alkalinity. It is designed for analysis of wastewater and treated water, as well as natural and purified water. It can be used for water with alkalinity concentration of up to 20 mmol/l. (Water quality. Determination of alkalinity. Part 1: Determination of total and composite alkalinity (ISO 9963-1:1994), u.d.)

3.3.3 Total Phosphorus

Since phosphorus (total phosphorus) is the main regulated component in WWTP, its monitoring is of great importance. As it was mentioned above, in Chapter 2.3.2 phosphorus is responsible for the eutrophication of world oceans. In view of this, recent trends are aimed at reducing the limits of phosphorus content. (Phosphorus Analysis in Wastewater, 2015)

To determinate phosphorus LUVY uses the standard ISO 6878:2004 that could be described as "specifies methods for the determination of orthophosphate, orthophosphate after solvent extraction, hydrolysable phosphate plus orthophosphate, and total phosphorus after decomposition". The citation was taken from (SFS Standard webstore, u.d.). The methods are applicable to all kinds of water including seawater and effluents. The same method is used for measurements the total soluble phosphorus.

The difference between total phosphorus and total soluble phosphorus is that the first one is a common indicator of all forms of phosphorus in the studied sample. The second one is the part of phosphorus compounds that are absorbed by plant cells. (Carlson, 1996, s. 96)

3.3.4 Chemical Oxygen Demand COD

COD is defined as the amount of oxygen equivalents consumed in the chemical oxidation of organic matter by a strong oxidant (e.g., potassium dichromate). From: Encyclopedia of Analytical Science, Second Edition, (Paul Worsfold, 2005)

COD is a measure of dissolved oxygen that is needed in the water to oxidize chemical organic materials. The more organic substances are presented in wastewater, the higher COD is.

LUVY using the ISO Standard - ISO 15705:2002 (ISO Standart orginzation, 2002)

3.3.5 Biochemical oxygen demand BOD

BOD – is an important environmental indicator for estimation of pollution level in wastewater samples. It indicates the amount of oxygen required by microorganisms and bacteria contained in wastewater for the biochemical decomposition and transformation of organic matter in aerobic conditions. From: Encyclopedia of Analytical Science, Second Edition, (Paul Worsfold, 2005)

The standard SFS-EN 1899-1:1998 (TL64) is used for estimation of the BOD in laboratories. This European Standard indicates a clarification of biochemical oxygen needs of wastewater. (SFS Standard webstore, u.d.)

3.3.6 Total Nitrogen

The Nitrogen is an important nutrient for animals and plants. It plays major role in biological process of treatment in wastewater treatment plant.

Nitrogen and its compounds enter wastewater from various sources. These are household drains from toilets and kitchens. Since nitrogen is one of the most common substances on Earth, there is no shortage of it in wastewater. In our case, wastewater that comes from the slaughterhouse is added to household nitrogen compounds. Feces and urine of animals are stored in the settling tanks at enters the sewage system.

Total Nitrogen is the sum of NO_2-N nitrite-nitrogen, NO_3-N nitrate-nitrogen, $NH_4 - N$ ammonia-nitrogen and nitrogen (N) bonded in organic. Nitrogen usually can be recognized in four different forms in wastewater, all four forms in most cases analysed separately and Ntot then calculated as a sum of all forms. (ChemScan, INC., 2022)

3.3.7 Ammonium $NH_4 - N$

Nitrogen (N), ammonia (NH_4+) and its compounds are nutrients for algae and plants. Their presence in wastewater can have a negative impact on the environment. Excessive accumulation of nitrogen, ammonia and other nitrogen compounds in wastewater eventually leads to explosive plant growth and algal blooms in reservoirs receiving wastewater. This leads to eutrophication, a decrease in oxygen levels, and death of fish and other aquatic organisms. Ammonium nitrogen is often found in wastewater as a result of household, livestock, and agricultural activities.

$NH_4 - N$ - is the nitrogen content of ammonium ions. In wastewater treatment technology and in our example study, only the nitrogen content in ammonium $NH_4 - N$ are reported.

LUVY laboratories are using the standard for determination the of ammonium $NH_4 - N$: SFS 5505:1988 (TL64).

The main reason for using two different test methods is a significant difference in the concentrations of the substances tested. The incoming wastewater stream brings significant concentrations of nitrogenous compounds into the treatment plant. At the outlet, most of it is removed by the treatment and the concentration drops many times over. The sensitivity of the test methods described in the standards varies. The range of operating concentrations of a method is not suitable for detecting very low concentrations.

3.3.8 The sum of nitrate (NO_3-) & nitrite ($N0_2$-) nitrogen

Nitrates (NO_3-) and nitrites ($N0_2$-) are salts of nitric and nitrous acid. They are formed in wastewater during the oxidation of ammonium nitrogen. Ammonium has already been described in detail in this paper. Now we will look in general at the result of the oxidation processes of ammonium.

Both nitrates and nitrites are carcinogenic and highly toxic substances that cause severe damage. (Breysse, 2017)

Denitrification - the bioprocess of converting nitrates (NO_3-) and nitrites ($N0_2$-) into nitrogen (N) gas, uses microorganisms (active sludge) with an increased content of organisms that work in an oxygen-free (anaerobic) environment. They need oxygen for their life, but they do not take it from the atmosphere, but by releasing oxygen molecules from compounds of nitrates (NO_3-) and nitrites ($N0_2$-).

The LUVY laboratory uses a method for determining the concentration of nitrite and nitrate according to ISO 13395:1996. This ISO standard specifies a method for determining nitrite(N), nitrate(N) or the sum of both that fit into different types of water such as groundwater, drinking water, surface water and wastewater.

Concentrations can range from 0.01 mg/l to 1 mg/l for nitrite(N) and from 0.2 mg/l to 20 mg/l for nitrite/nitrate(N), each in the undiluted sample.

3.3.9 pH

pH, quantitative measure of the acidity or basicity of aqueous or other liquid solutions. (britannica science pH, u.d.) pH is an important indicator in wastewater treatment. By regulating pH, it is possible to remove various types of contaminants such as heavy metals and/or organic compounds and others from wastewater during treatment. Therefore, it is important to monitor and control the pH of income flow.

Furthermore, an appropriate pH value leads to an increase in microbiological activity and promotes the degradation of waste materials.

Two different methods were used to collected pH data during the study.

First, the LUVY laboratory analysed wastewater samples using the standard SFS 3021:1979 (TL64)

The second method was a portable pH analyser: "VWR pHenomenal pH1000H", which was used directly at the time of sampling. The measured data were recorded directly at the time of collection of each batch of samples. The arithmetic mean of the sample was then calculated and recorded. The laboratory results and the results obtained with the help of the device will be compared further.

3.3.10 Electrical conductivity

Electrical conductivity (EC) is an important indicator that can help analyse the proportion of various pollutants in wastewater. The more different dissolved substances, metal ions, salts and other minerals contaminate the aqueous solution with chemicals, the higher the EC value. Conductivity is the value for the ability of a liquid to pass an electric current.

The LUVY used the SFS-EN 27888:1994 standard that are related with ISO 7888:1985.

3.3.11 Soluble precipitation metal (Fe / Al)

Various impurities dissolved in water can be converted by chemical precipitation into solid species, which are then precipitated and removed from the wastewater. (B.Zueva, 25 May 2018). During the purification process, as described in section 2.3.2 Chemical process, RAKE is added for better deposition, which is automatically dosed depending on the amount of incoming flow. Iron sulphide $Fe_2(SO_4)3$ helps to significantly reduce the time and improve the coagulation and flocculation of dissolved trace element impurities. However, this also increases the proportion of dissolved iron molecules in the treated water. They should be removed together with the spent activated sludge for further processing in municipal WWTP. In order to control and, if necessary, correct the dose of iron sulphide added, a condition for the control of dissolved precipitating iron was set at the request of the authorities.

3.3.12 Escherichia coli sampling

Escherichia coli bacteria are one of the indicators of water quality. This bacterium lives in the rectum of warm-blooded organisms such as cattle and humans. Their presence in water indicates contact of the water with faces. According to the European Bathing Water Quality Directive 2006/7/ EC a standard for the presence of bacteria in inland waters is introduced. The stream is definitely an inland water body. (Standard, 2012)

This parameter has no direct influence on the assessment of the effectiveness of wastewater treatment by a new wastewater treatment plant. However, it allows you to assess the condition of the water body as a whole.

The study is conducted in accordance with ISO 9308-2:2012 Water quality - Counting of E. coli and coliform bacteria - Part 2: The method of most probable quantity.

3.3.13 Determination of dissolved oxygen. Iodometric method

Dissolved oxygen in water is an indicator of the condition of a body of water. It can be an indication of the ability of aquatic organisms to live in the water. The Winkler test is used to determine the concentration of dissolved oxygen in water. This test is well known and requires not only water sampling for the sample, but also additional measures with the sample at the time of sampling.

Special glass vessels of 100 ml and two reagents with a pipette were obtained for the test in the laboratory.

It is necessary to collect a full vessel of water without leaving room for air. Remove the air bubbles. Add 1 ml of manganese sulphate and 1 ml of alkali iodide aside reagent. You have to dip the pipette 1 cm deep into the water in the vessel. Avoid that water bubbles get into the vessel. After adding the first reagent, shake the vessel thoroughly and repeat after adding the second reagent. Close the bottle tightly with a lid.

4 Result

During 5 months of collecting samples, 4 days were spent for sampling in Normal Days and 4 days for sampling in Slaughter Days. On each day, 24 research orders were collected and sent to the laboratory. Each study day included from 6 to 8 liters of collected wastewater samples. The total number of parameters analysed during the whole study was 269 units.

In addition, 14 parameters in each sample were analysed. Each of them was collected as a result of several samples in 4 repetitions. The data is given in tables (**Table 77~~Table 7~~**).

Additional parameters were collected during the days of slaughter. The data is presented in the table (**Table 88~~Table 8~~**).

Table 77. Results of the Normal Day, Summary

		Input	Input	Input	Input	Output	Output	Output	Output
	Value	7.7.2021	23.8.2021	26.9.2021	10.10.2021	8.7.2021	24.8.2021	27.9.2021	11.10.2021
Electrical conductivity (25oC)	mS/m	74,4	103	92,6	85,9	60,7	85,8	79,4	88,9
Water temperature	°C	19,0	17,3	14,5	14,0	19,4	18,0	15,6	16,1
pH (room temperature)	pH	7,4	7,7	7	7,6	6,0	6,7	5,7	7,1
pH, average during sampling	pH	7,0	7,1	7,5	7,6	5,5	6,2	5,1	6,7
Alkalinity	mmol/l	4,3	5,8	4,2	5,2	0,11	0,25	0,025	0,75
Suspended Solid	mg/l	190	95	130	190	14,0	14	4,2	5,9
COD	mgO_2/l	610	450	690	980	25,0	29	20	30
BOD	mgO_2/l	260	230	350	390	3,1	4,2	2,3	2,3
Total phosphorus	mgP/l	10	27		8,0	0,4	0,75		0,63
Total soluble phosphorus	mgP/l	8,7	26		6,2	0,049	0,45		0,42
Total Nitrogen	mgN/l	42	69	63	57	2,7	30	22	23
Ammonium nitrogen NH_4-N	mgN/l	33	58	49	43	0,3	0,097	0,088	0,066
(NO_3+NO_2)-N	mgN/l	0,007	0,005	0,014	0,005	1,7	29	23	22
Fe, soluble (0,45µm)	µg/l	0	0	0	0	58	720	380	180

Table 88. Results of the Slaughter Day, Summary

		Input	Input	Input	Input	Output	Output	Output	Output
	Value	29.6.2021	10.8.2021	27.9.2021	25.10.2021	30.6.2021	11.8.2021	28.9.2021	26.10.2021
Electrical conductivity (25oC)	mS/m			94,6	82,2	69,2	75,3	82,6	77,2
Water temperature	°C	18,3	17,8	13,9	11,6	18,7	19,9	15,5	13,1
pH (room temperature)	pH	6,9	7,5	6,2	7,1	6,5	6	6,4	6,1
pH, average during sampling	pH	7,1	7,4	6,8	7,1	6,0	5,3	5,7	5,5
Alkalinity	mmol/l	5,1	4,3	2,6	4,0	0,32	0,10	0,13	0,081
Suspended Solid	mg/l	650	190	210	320	11,0	21	6,5	5,4
COD	mgO_2/l	1900	1400	1500	2500	30,0	60	15	17
BOD	mgO_2/l	830	660	950	1710	4,0	8,1	1,8	1,6
Total phosphorus	mgP/l	18	10	33	22,0	0,6	0,65	0,42	0,18
Total soluble phosphorus	mgP/l	14,0	9,3	30	21	0,35	0,14	0,14	0,075
Total Nitrogen	mgN/l	130	51	90	210	7,2	24	23	25
Ammonium nitrogen NH_4-N	mgN/l	53	51	36	120	6,1	9,4	0,068	0,065
(NO_3+NO_2)-N	mgN/l	0,008	0,029	0,036	0,024	0,5	13	23	24
Fe, soluble (0,45µm)	µg/l	0	0	0	0	6	490	38	160

4.1 Presentation of results in graphs and tables

Below, the data is presented in the form of diagrams and some explanations.

4.1.1 Before vs after treatment

The results obtained after laboratory analysis were processed in order to construct graphs. These graphs clearly demonstrate the difference in values of the studied parameters. It is clearly visible how values are changing. This indicates that the process of water treatment entering the treatment facilities is underway.

4.1.2 Suspended solids

A Normal Day

There are some noticeable differences in the values for the number of suspended solids in the incoming wastewater. This is typical for wastewater, as it is heterogeneous in its composition. The results of treated water sampling are relatively stable. The graph (Figure 20~~Figure 20~~) during Normal Days shows that in all four repetitions of sampling "before and after" there is a significant decrease in the number of solid particles. In addition, pre-setting of the WWTP operation took place during the intervals between samplings. As a result, the graph shows a decrease in the number of suspended solids from 14 to 5.9. This fact indicates an increase in efficiency of the purification process.

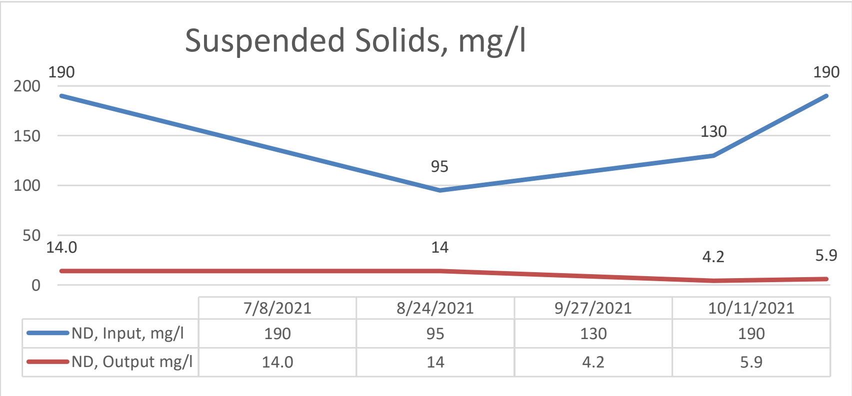

Figure 20 Suspended Solids during Normal Days.

A Slaughter Day

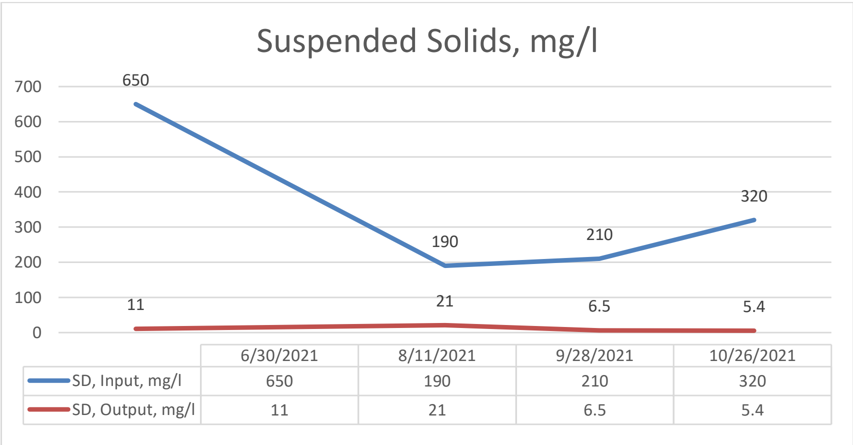

Figure 21 Suspended Solids during Slaughter Day

On slaughter days, the solid particles in the wastewater are significantly higher compared to the values in the incoming wastewater (Figure 21~~Figure 21~~). Despite the increase in the number of solid particles in the effluent, there is no significant increase in suspended solids in treated water. And in the last months of sampling, the values are similar compared to the ND samples.

According to legislation, a value of 35 mg/l is considered as a threshold. Details can be found in section 2.4 Legislation~~Legislation~~ . At maximum load on slaughter days, the treatment process in the WWTP performs more efficiently than requested by threshold values (Figure 22~~Figure 22~~, Figure 23~~Figure 23~~).

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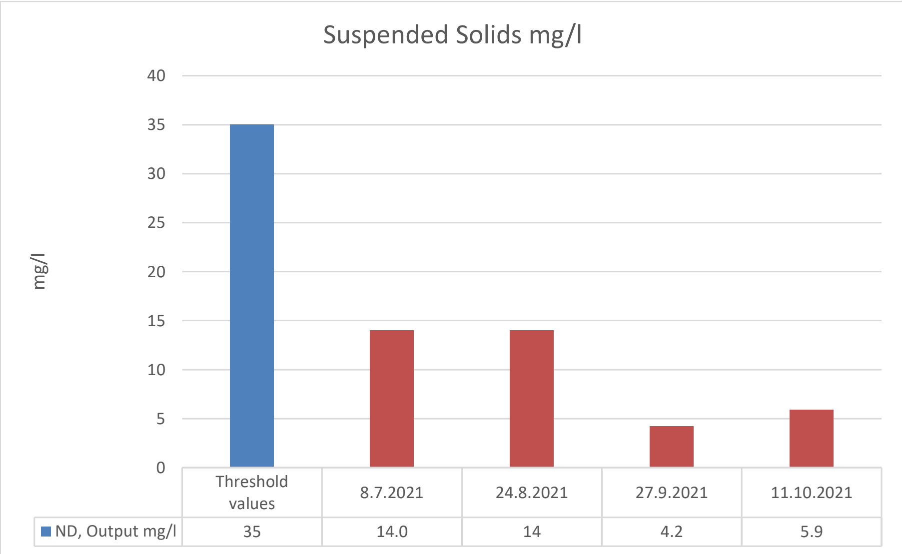


Figure 22 Suspended Solids. Thresholds values and ND data

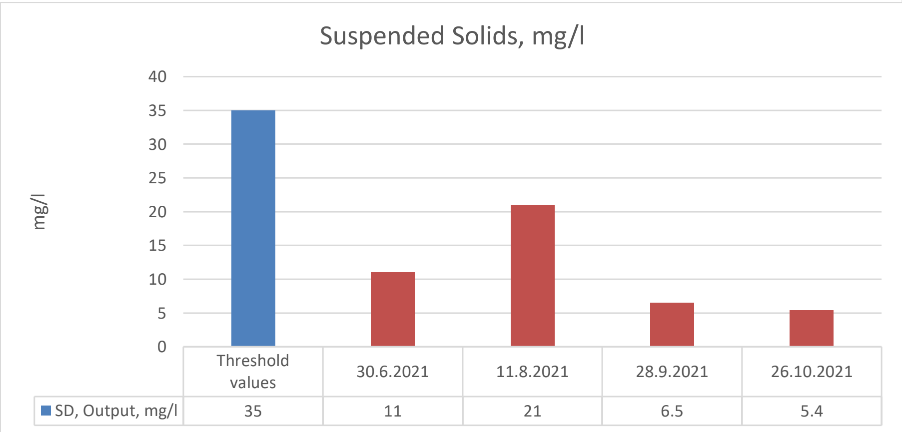


Figure 23 Suspended Solids. Thresholds values and SD data

The obtained data shows that the work of removing solid particles from wastewater is effective both on ND and SD.

4.1.3 Alkalinity

The obtained data of alkalinity analysis clearly shows a decrease in the alkalinity of water after the purification process. As it was mentioned earlier in the section Alkalinity 3.4.2, this is one of the ways to measure the readiness of treatment facilities for effective treatment.

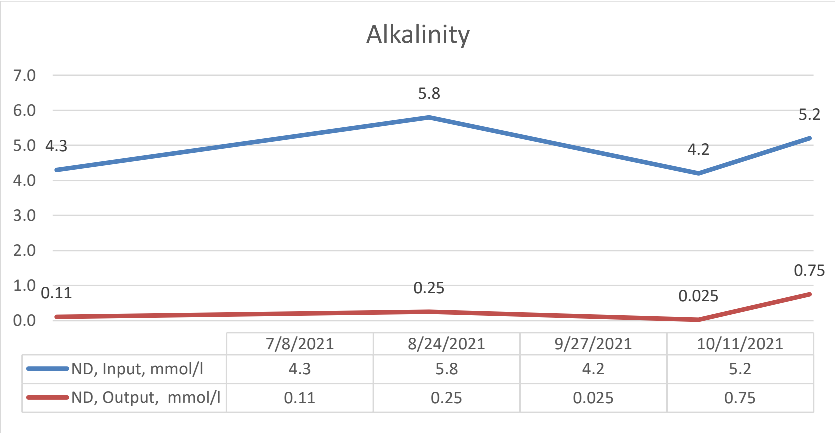


Figure 24 Alkalinity Normal Day results

The results were displayed on the graph (Figure 24~~Figure 24~~, Figure 25~~Figure 25~~) that shows a similar picture. And in case of ND and SD, there is a significant decrease in the level of alkalinity. In general, we can conclude that the system works efficiently and copes with the load.

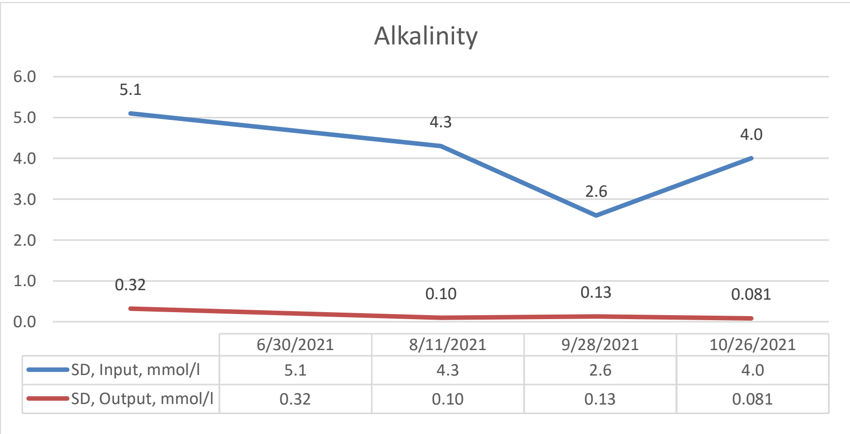
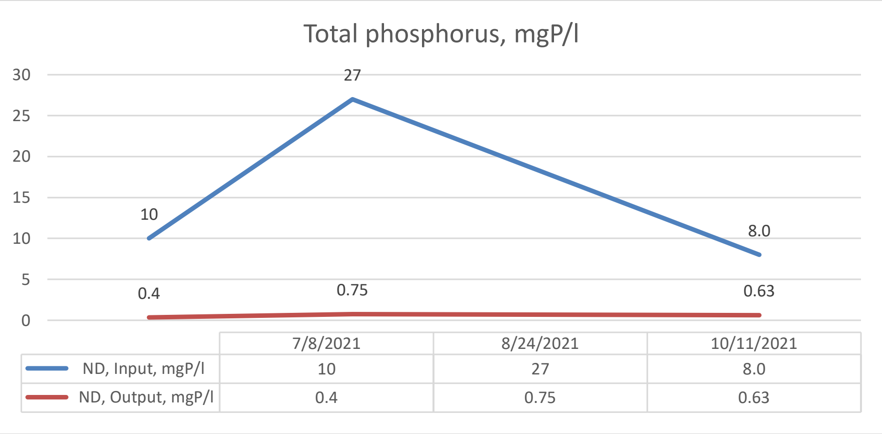


Figure 25 Alkalinity Slaughter Day results

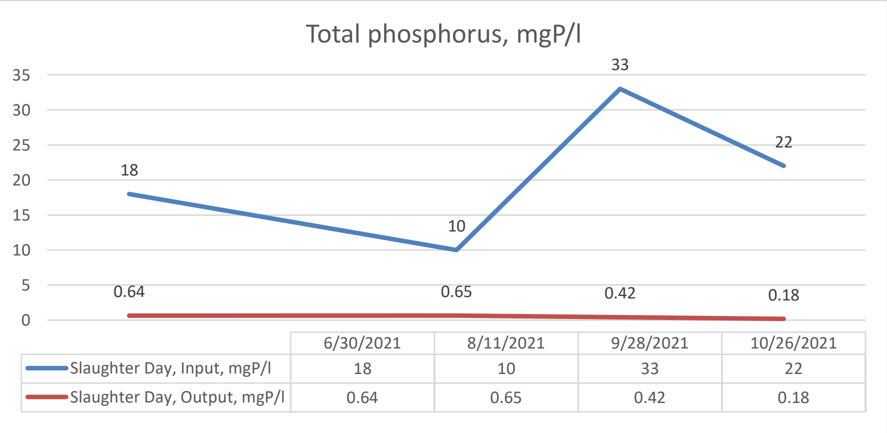
4.1.4 Total phosphorus

The data of Total phosphorus (Figure 26~~Figure 26~~, Figure 27~~Figure 27~~) shows the significant reduction in amount of phosphorus in treated water samples.



	7/8/2021	8/24/2021	10/11/2021
ND, Input, mgP/l	10	27	8.0
ND, Output, mgP/l	0.4	0.75	0.63

Figure 26 Phosphorus total Normal Day results



	6/30/2021	8/11/2021	9/28/2021	10/26/2021
Slaughter Day, Input, mgP/l	18	10	33	22
Slaughter Day, Output, mgP/l	0.64	0.65	0.42	0.18

Figure 27 Phosphorus total Slaughter Day results

Threshold values for phosphorus have been set on the level 0,7 mg/l.

The results of the analysis show that the values in ND and SD levels are almost twice as low as threshold values. This indicates a significant efficiency of the treatment process.

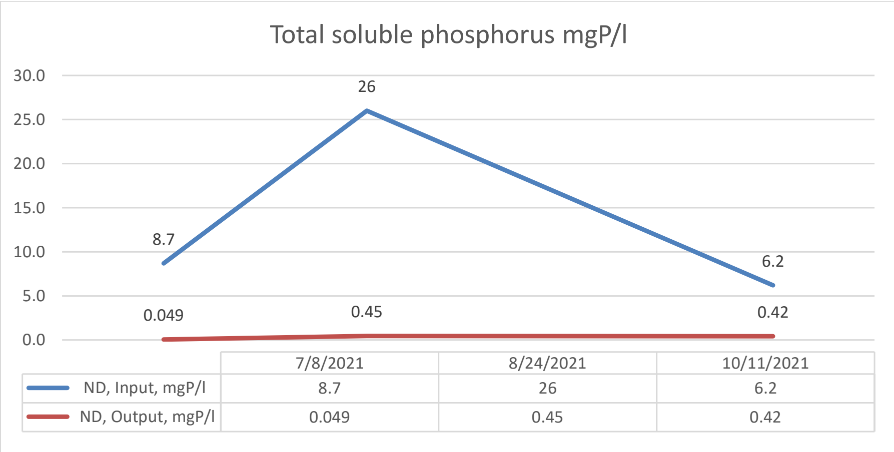


Figure 28. Results of total soluble phosphorus in ND

Total soluble phosphorus that was mentioned earlier is all phosphorus bound in compounds that can be consumed by plant organisms. The parameter has no threshold values (Figure 28~~Figure 28~~, Figure 29~~Figure 29~~)

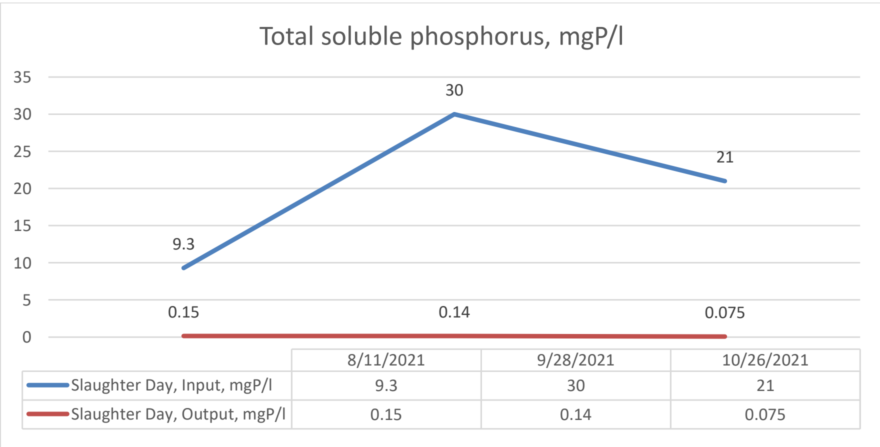


Figure 29. Results of total soluble phosphorus in SD

The results of the analysis and their subsequent output in the form of a graph show a decrease in the phosphorus content in the treated water.

Comparing with threshold values (Figure 30~~Figure 30~~, Figure 31~~Figure 31~~).

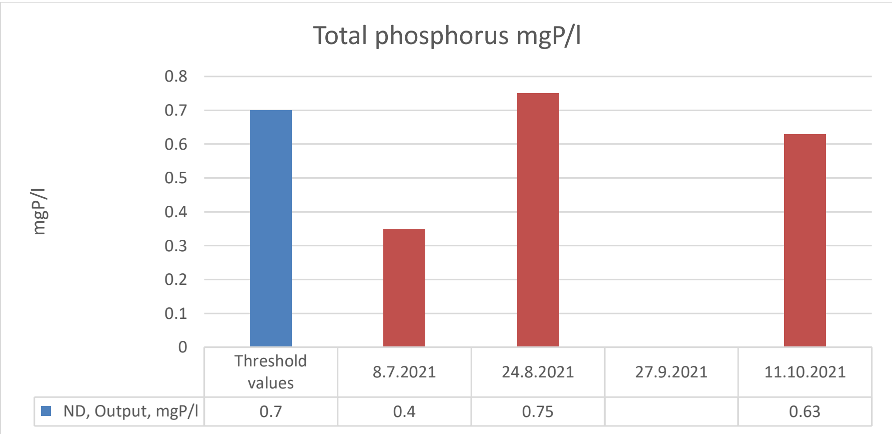


Figure 30. Total phosphorus. Thresholds values and ND data

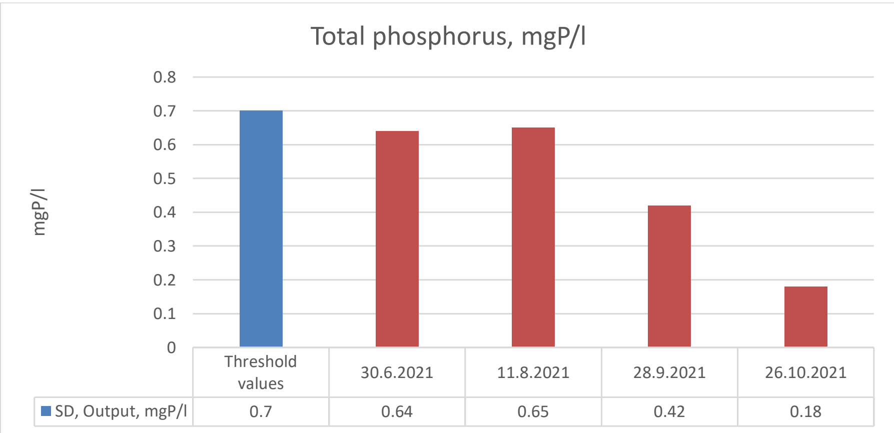


Figure 31. Total phosphorus. Thresholds values and SD data

To sum it up, the results of phosphorus analysis clearly show a decrease in pollution level in the treated water. The treatment plant effectively removes phosphorus.

4.1.5 Chemical Oxygen Demand

COD is one of the five most important indicators for assessing the quality of wastewater treatment. In section Chemical Oxygen Demand COD~~Chemical Oxygen Demand COD~~ the number of the oxygen equivalent consumed during chemical oxidation of organic matter by a strong oxidizer was described in detail.

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Blood, protein and fat which are abundant in the sewage from the slaughterhouse naturally increases the COD values. A special fat load can be seen in the COD values in the wastewater of the meat processing industry.

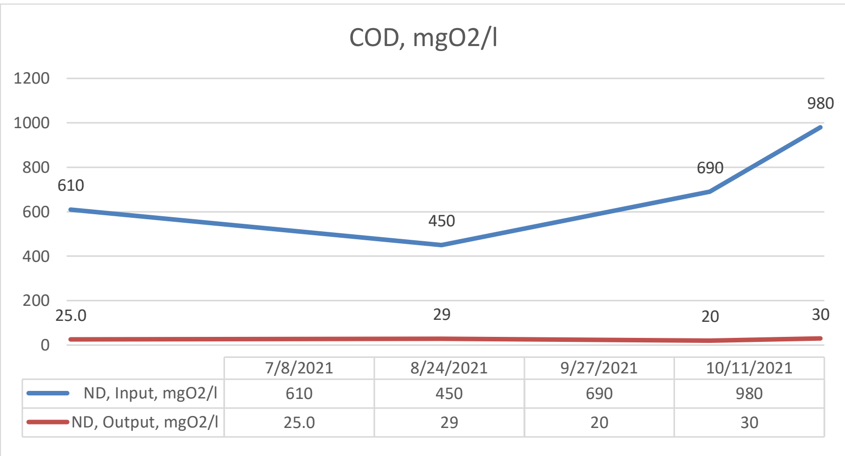

Figure 32. Results of COD in ND

The value of this parameter increases multiple times when wastewater enters the treatment facilities. This is clearly seen in the graphs below (Figure 32~~Figure 32~~, Figure 33~~Figure 33~~). Input values, the blue line. The growth in the days of slaughter is almost three times higher.

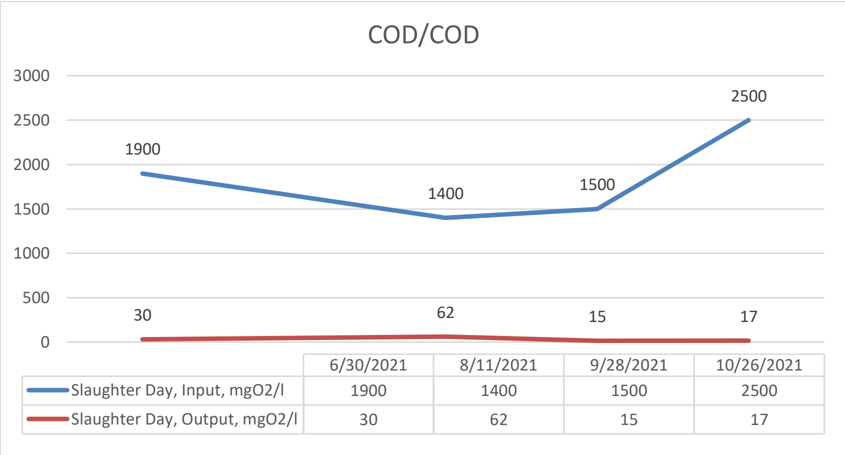

Figure 33. Results of COD in SD

The increase may also be because of the fact that a significant amount of warm water is also supplied with incoming waste, which affects dissolution of oxygen.

Let us compare COD income levels with the data of Finnish Water Utilities Association (Finnish Water Utilities Association, 2018) indicated in section 2.4 Legislation~~Legislation~~. At the same time, the threshold values for municipal treatment plants should be 125 mgO_2/l. It can be seen that the incoming wastewater to the treatment plant according to the COD parameter significantly exceeds the median industry values equal 596 mgO_2/l. This indicates that the system is really experiencing significant loads, especially during the slaughterhouse operation (Figure 34~~Figure 34~~, Figure 35~~Figure 35~~).

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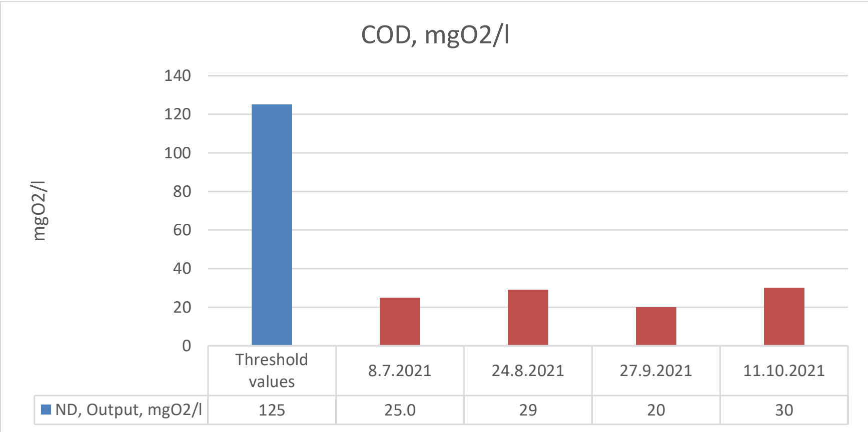


Figure 34. COD. Threshold values and ND data

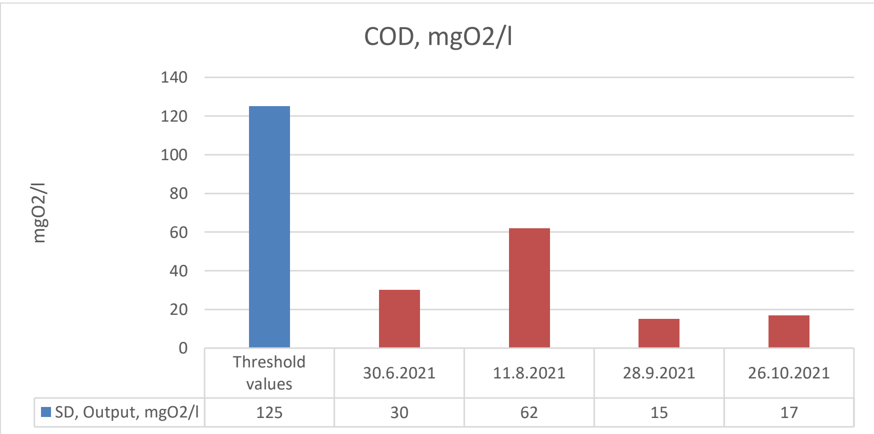


Figure 35. COD. Thresholds values and SD data

At the same time, the data obtained from the analysis of water from the output shows that the updated treatment plant copes with the tasks of wastewater treatment.

4.1.6 Biochemical oxygen demand BOD

BOD is the most important indicator related to the effectivity of the treatment plant. The collected and processed data in the study shows high BOD values in the wastewater from Västankvarn. On slaughter days the concentration of pollutants increases, leading to multiple increase in BOD values. This is shown in the graphs in (Figure 36Figure 36, Figure 37Figure 37) where a significant increase in BOD values is seen on the days of slaughter.

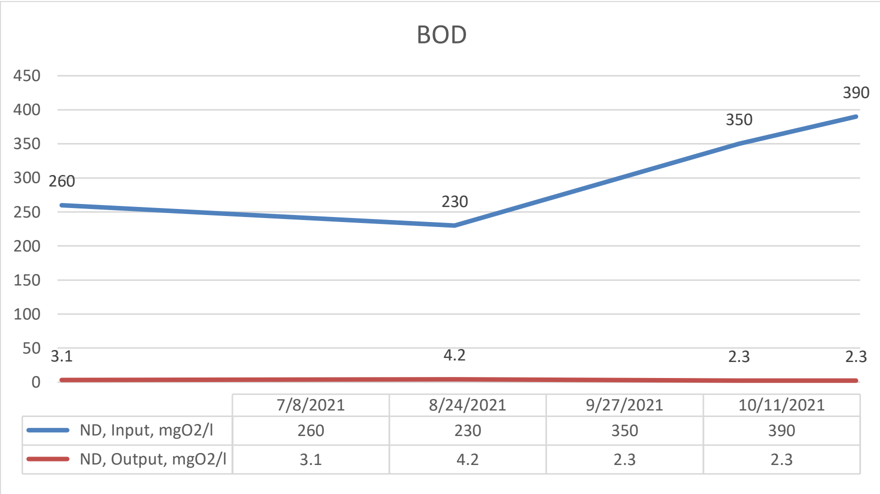


Figure 36. Results for BOD in ND

The situation is the same as with COD. The slaughter process requires a significant amount of warm water and brings a significant contribution to such highly concentrated pollutants as blood, fat, urine and feces. It leads to a large amount of liquid waste falling in its final form into wastewater, into the sewer and then to treatment facilities. The wastewater saturated with organic compounds requires more oxygen to decompose with the help of microorganisms.

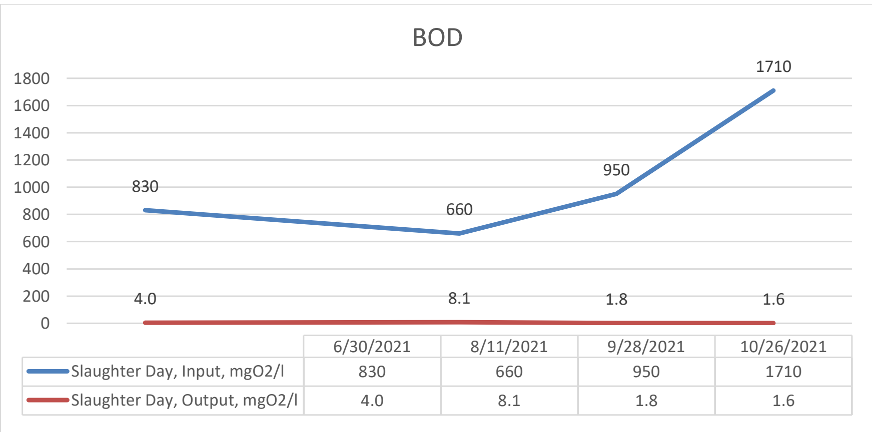


Figure 37. Results for BOD on SD.

However, when analysing the BOD values, we can also rely on the threshold values that are defined in the legislation and specified in the decision on the reconstruction of treatment plant.

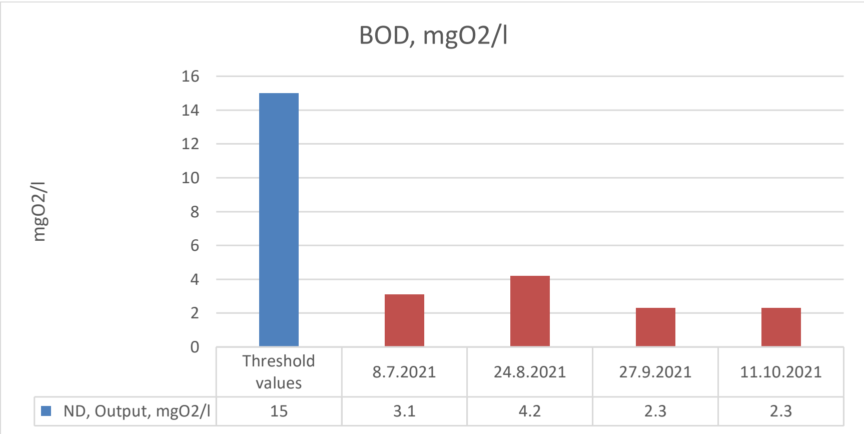


Figure 38. Thresholds values BOD and ND data

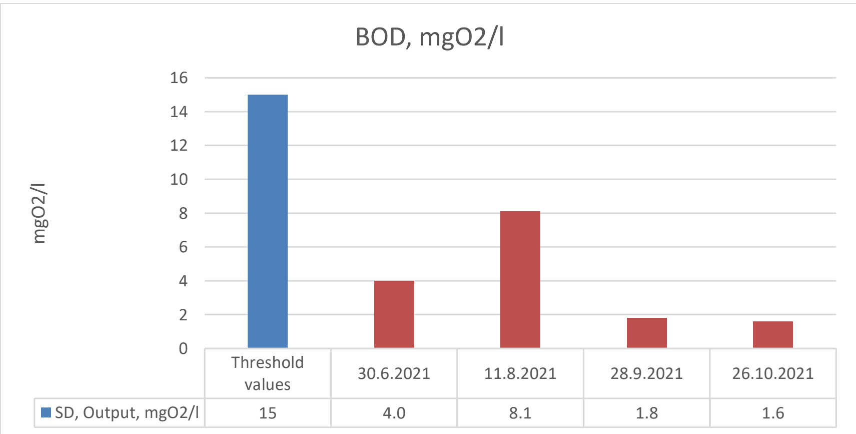


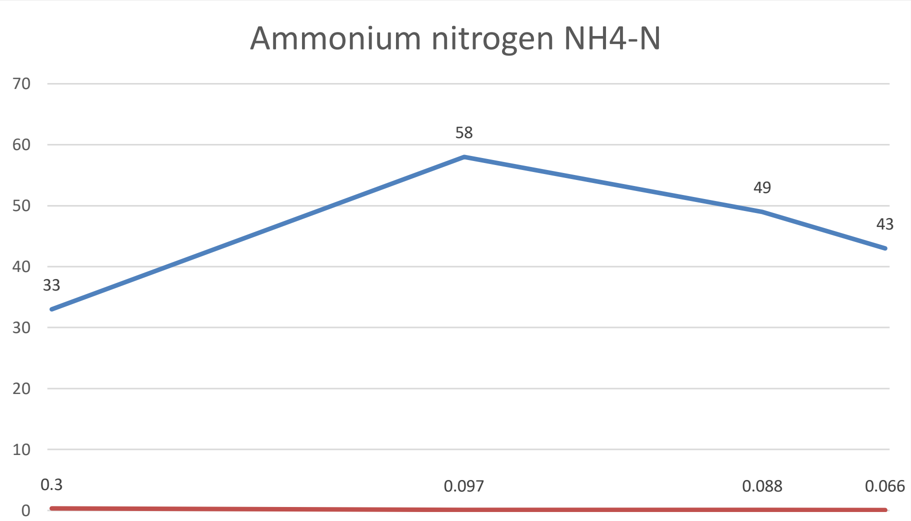
Figure 39. Thresholds values BOD and SD data

The minimum concentration of BOD ≤ 15 mgO_2/l is achieved based on the results of the analysis of treated wastewater. The output data shows a range from 1.8 mgO_2/l to 8.1 mgO_2/l, which is included in the required values. It is possible to draw conclusions based on the data that the system works efficiently.

4.1.7 Ammonium $NH_4 - N$

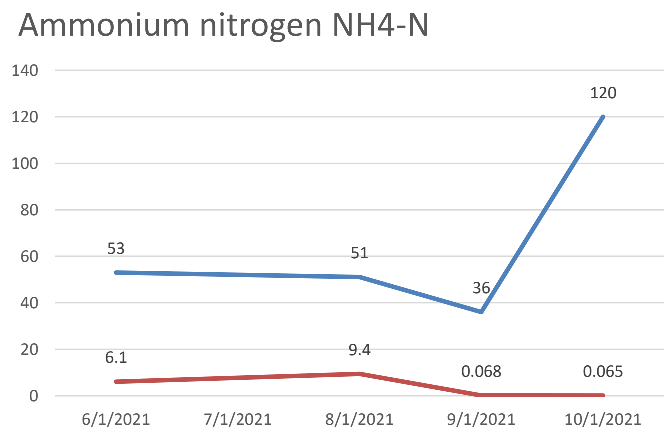
NH4-N is the nitrogen content of the ammonium ion. Ammonium ions in wastewater in Västankvarn, as well as Nitrogen in general, are a typical pollutant of wastewater. Due to their high activity and ability to cause significant damage to the environment, they are removed during the cleaning process. As can be seen in the graphs, their concentration in SD increases significantly compared to ND.

As a result of collecting analyses of the effluent, encouraging results were obtained. Thanks to a biological process, ammonium $NH_4 - N$ is removed from wastewater.



	7/8/2021	8/24/2021	9/27/2021	10/11/2021
ND, Input, mgN/l	33	58	49	43
ND, Output, mgN/l	0.3	0.097	0.088	0.066

Figure 40. Results of $NH_4 - N$ Ammonium in ND



	6/30/2021	8/11/2021	9/28/2021	10/26/2021
Slaughter Day, Input, mgN/l	53	51	36	120
Slaughter Day, Output, mgN/l	6.1	9.4	0.068	0.065

Figure 41. Results of $NH_4 - N$ Ammonium in SD

The results show that the process of ammonium nitrogen $NH_4 - N$oxidation proceeds efficiently from the maximum values of 120 to 0.065 mgN/l. The process of ammonium nitrogen $NH_4 - N$ oxidation leads us to the following parameter.

4.1.8 The sum of nitrate (NO_3-) & nitrite ($N0_2$-) nitrogen

Denitrification taking place as part of the bioprocess of wastewater treatment. In the process of denitrification, nitrogen (N) compounds are processed into nitrogen and oxygen by means of activated sludge. ∑ nitrate (NO_3-) & nitrite ($N0_2$-) nitrogen parameter is essentially an indicator of the efficiency of activated sludge in a WWTP.

During nitrification, ammonia and ammonium are converted to nitrate (NO_3-) in aerobic by nitrifying bacteria. During denitrification, nitrite ($N0_2$-) finally passes into gas form nitrogen (N_2), it is removed from the system under oxygen-free conditions. Monitoring of nitrates in an oxygen-free zone is of great importance, because it allows you to determine the effectiveness of denitrification.

As described in section 2.3.1 nitrification denitrification is the biological stages of decomposition of nitrogen compounds. The task of measuring the total nitrate (NO_3-) and nitrite ($N0_2$-) is precisely designed to show that the process of formation of these products.

This monitoring shows the presence of by-products in the system. In the future, they can be recycled into secondary settling tanks in large wastewater treatment systems. In this compact system, they are released outside. They do not bind in a swampy zone and where they transform into nitrogen (N) and water (H_2O) under anaerobic conditions and in the presence of organic carbon (C).

The results in the diagram (Figure 42Figure 42, Figure 43Figure 43) show that there is practically no nitrate (NO_3-) and nitrite ($N0_2$-) ions at the entrance to the treatment facilities. These concentrations are shown in very small concentrations. In the future, during the launch of bioprocess and decomposition of ammonium and ammonium, significant concentrations of nitrate (NO_3-) and nitrite ($N0_2$-) can be observed.

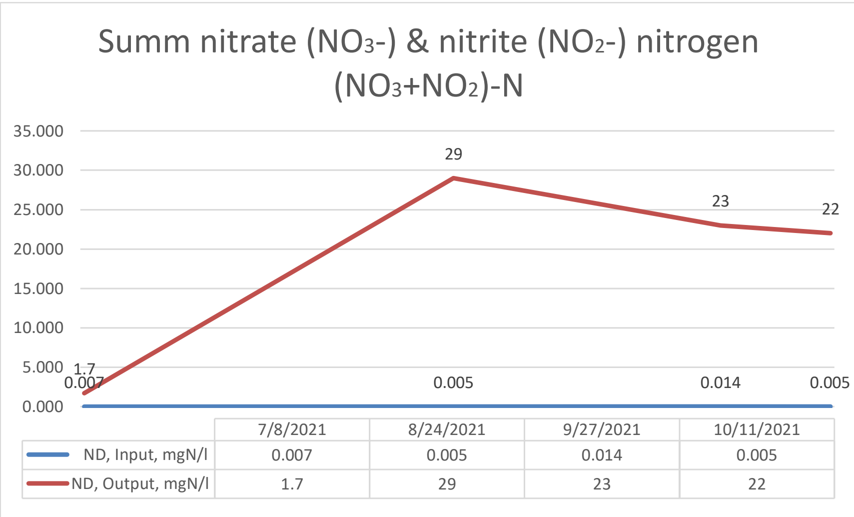
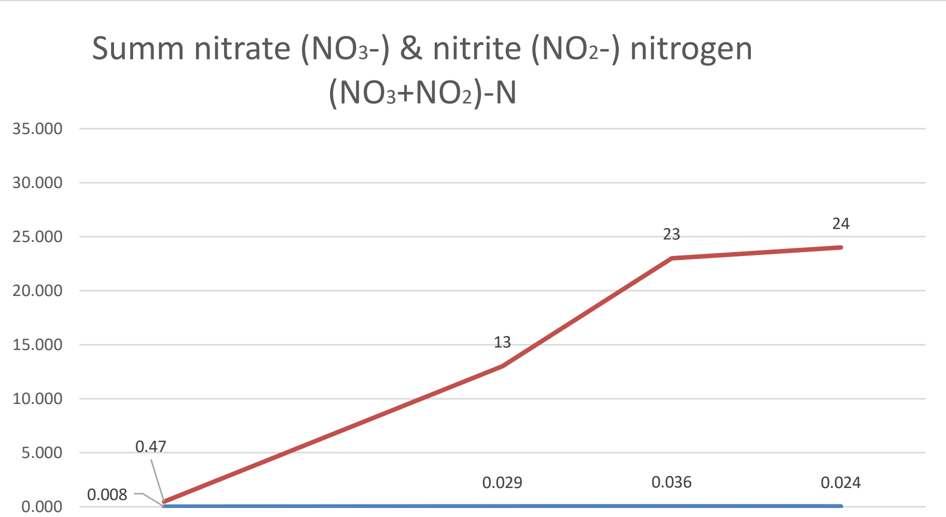


Figure 42. Results of sum of nitrates and nitrite (NO_3+$N0_2$)-N in ND



	6/30/2021	8/11/2021	9/28/2021	10/26/2021
Slaughter Day, Input, mgN/l	0.008	0.029	0.036	0.024
Slaughter Day, Output, mgN/l	0.47	13	23	24

Figure 43. Results of sum of nitrates and nitrite (NO_3+$N0_2$)-N in SD

4.1.9 Total Nitrogen, Ntot

Total nitrogen is one of those elements that is constantly monitored. As described in section 3.3.6, Nitrogen plays an important role in biological processes and is one of the building materials for living organisms. As a result, wastewater contains quite a lot of nitrogen compounds.

According to the decree "Government decree treatment of domestic waste water in areas outside sewage networks 157/2017", the nitrogen content in treated wastewater should be 40% lower compared to the nitrogen level in existing untreated wastewater.

However, the decision of the authorities on WWTP does not contain specific requirements for the nitrogen content in treated wastewater.

The graphs show that the values of the nitrogen level in incoming wastewater and treated wastewater differ significantly from ND and SD. The minimum difference was recorded in the situation of an SD day from 8/11/2021 when the nitrogen level in untreated wastewater was 51 mgN/l after treatment of 24 mgN/l. This corresponds to a treatment level of more than 52.92%. On the remaining days in both states, the nitrogen treatment level rises to 59-90%

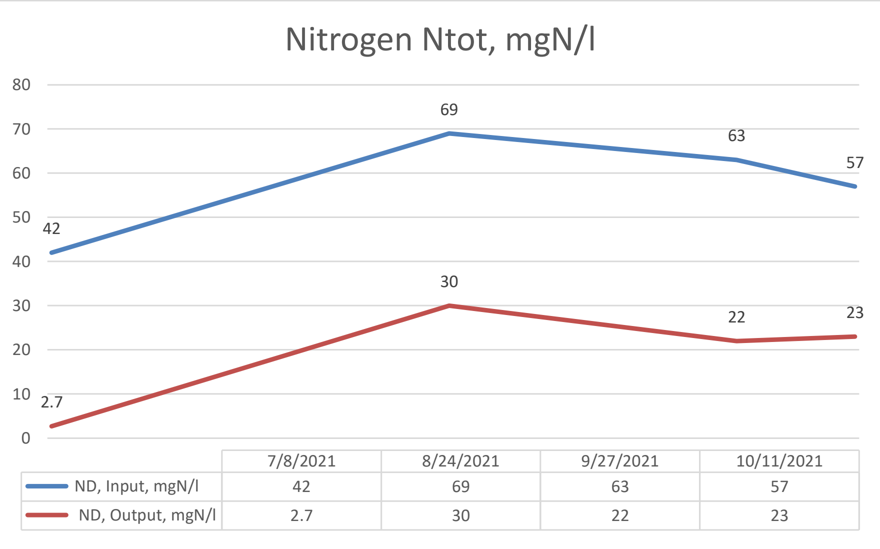


Figure 44. Results total Nitrogen in ND

In general, the graphs show that the treatment process significantly reduces the nitrogen level in both ND and SD. Treatment of nitrogen from wastewater falls within the threshold value and has a margin.

Summing up not only nitrogen but through his connections, we can say: nitrification shows high values (NO_3-) ad ($N0_2$-) this weekend. If we compare these data (NO_3-) and ($N0_2$-) with Ntot data. Based on this, it can be concluded that the level of nitrification is very high. If we also compare the data on ammonium $NH_4 - N$, then the reduction is very good - from 80 to 94%.

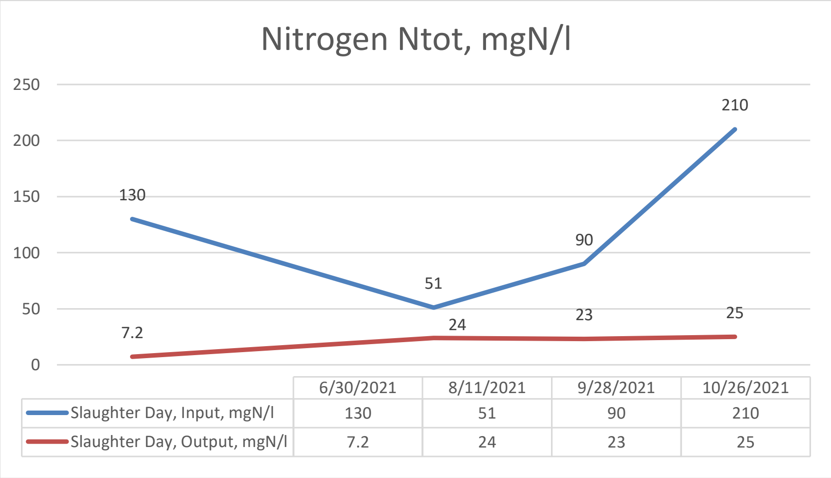


Figure 45. Results total Nitrogen in SD

The figures Figure 44 ~~Figure 44~~ and Figure 45~~Figure 45~~ show that the values of the nitrogen level in incoming wastewater and treated wastewater differ significantly from ND and SD. The minimum difference was recorded in the situation of an SD from 8/11/2021 when the nitrogen level in untreated wastewater was 51 mgN/l after treatment of 24 mgN/l. This corresponds to a treatment level of more than 52.92%. On the remaining days in both states, the nitrogen treatment level rises to 59-94% Figure 46~~Figure 46~~ and Figure 47~~Figure 47~~.

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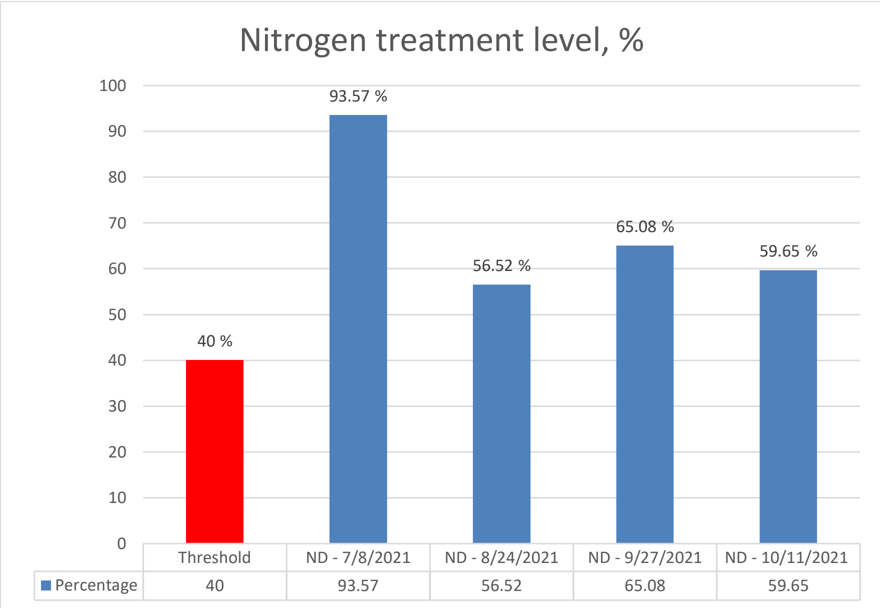


Figure 46. Thresholds values Ntot and ND data

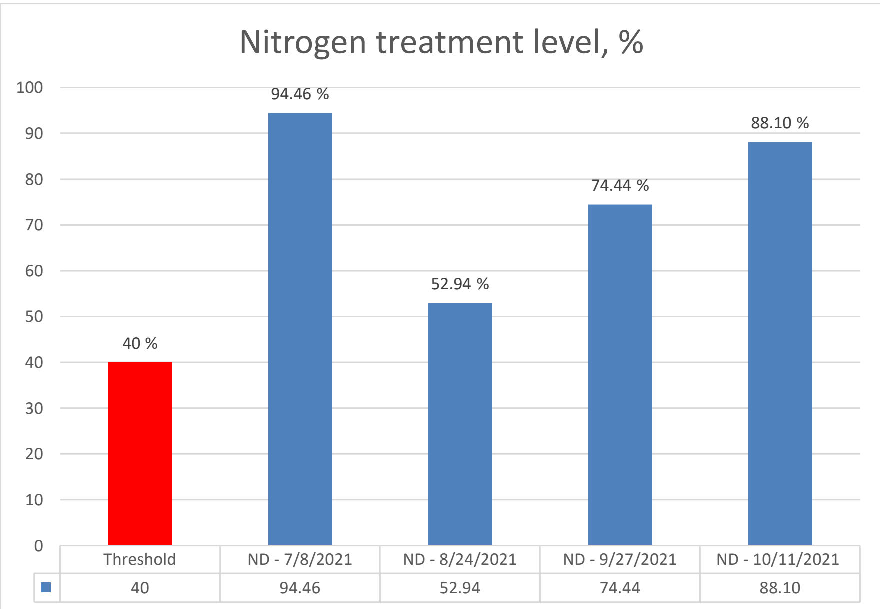


Figure 47. Thresholds values Ntot and SD data

In general, the graphs show that the treatment process significantly reduces the nitrogen level in both ND and SD. Treatment of nitrogen from wastewater falls within the threshold value and has a margin.

4.1.10 pH

In order to normalize the pH of wastewater, an acid solution is fed into the pre-tank. This is required for the normal bioprocess of organic decomposition. The point of preparation and dosing of the pH normalization reagent in automatic mode with the help of a multi-control system determines the pH of wastewater. Then the acid solution is supplied in exact accordance with the results obtained.

In our study, the pH was measured immediately upon sampling by pH analyser. This is shown in the (Figure 48~~Figure 48~~). With the help of continuous measurement, each repeated sample was measured for pH, the value was recorded and then the average pH level of all samples was calculated.

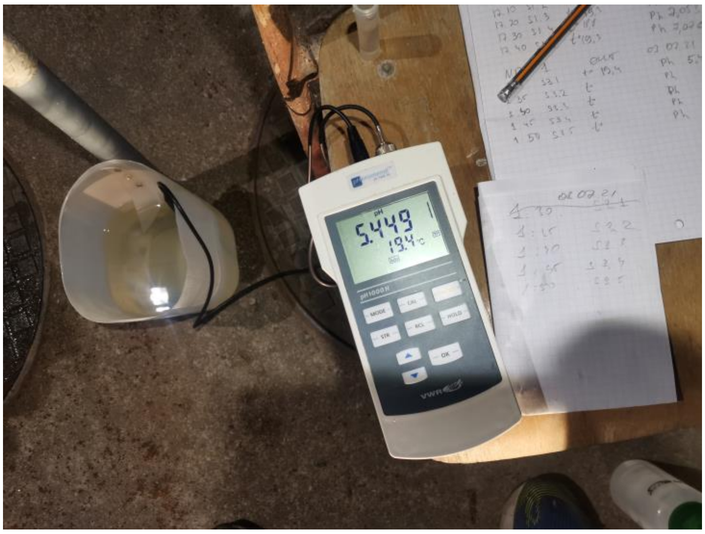
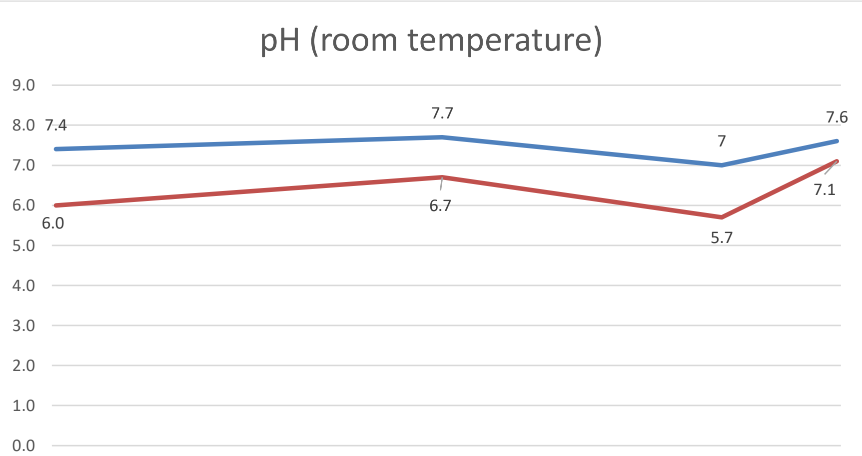


Figure 48 pH meter in process

pH was also measured in the laboratory. However, several hours passed between sampling and measurement in the laboratory, decomposition processes under the influence of time, temperature changes, lighting could lead to some changes in pH values. However, it is possible that the pH value has differences due to different measurement methods and equipment accuracy.

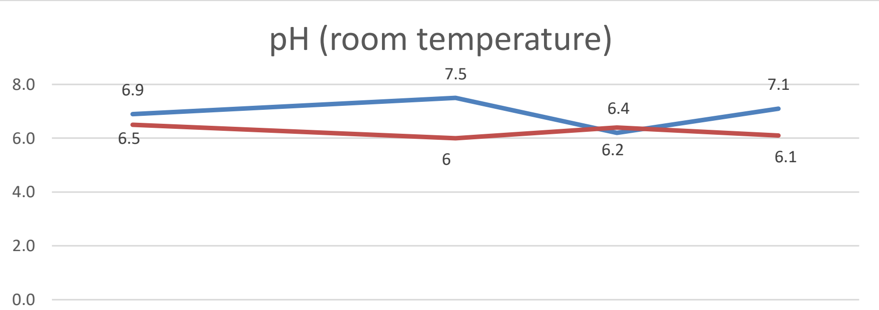
Active sludge fully functions within the pH range from 6.5 to 7.8. This is a neutral or slightly alkaline environment. Such conditions ensure the development of useful forms of activated sludge and its maximum ability to precipitate. If there is a pH shift to the acidic side, the metabolic reactions of floccule-forming bacteria are suppressed. With an increase in the alkaline medium, flocculation-forming bacteria increase the intensity of metabolic reactions, and even the death of activated sludge is observed.

As can be seen (Figure 49Figure 49) the incoming wastewater flow is in the pH range of 7, which means its value as slightly alkaline. Sometimes approaching pH 8, which makes the work of activated sludge less effective due to the above. The output shows that the medium is reduced to a slightly acidic pH value of 6. This is the most favourable environment for the development of microorganisms of actin sludge.



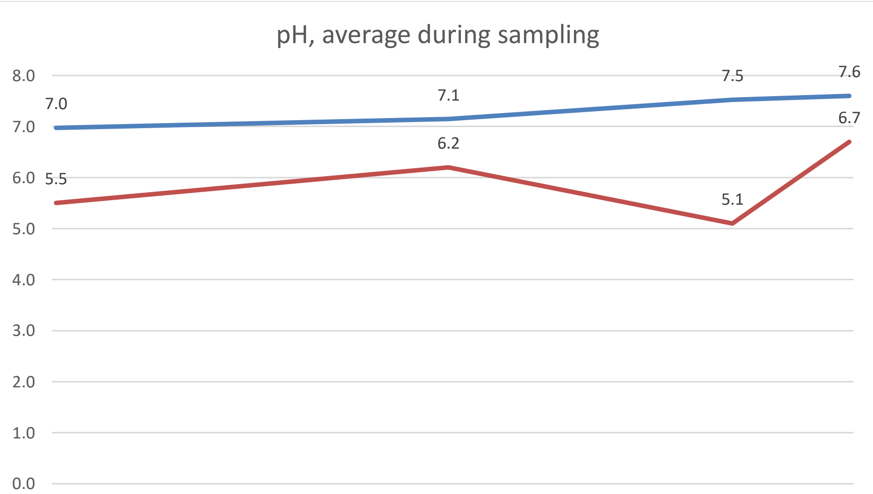
	7/8/2021	8/24/2021	9/27/2021	10/11/2021
ND, Input, pH	7.4	7.7	7	7.6
ND, Output, pH	6.0	6.7	5.7	7.1

Figure 49 pH LUVY lab in ND



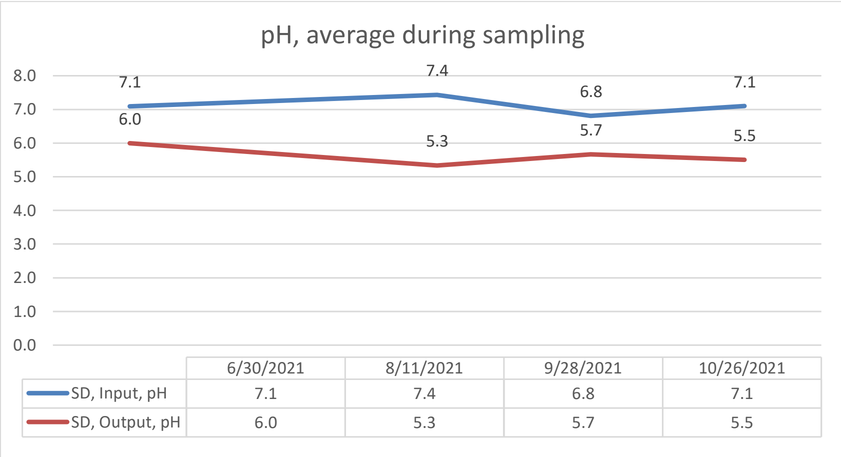
	6/30/2021	8/11/2021	9/28/2021	10/26/2021
SD, Input, pH	6.9	7.5	6.2	7.1
SD, Output, pH	6.5	6	6.4	6.1

Figure 50. pH LUVY lab in ND



	7/8/2021	8/24/2021	9/27/2021	10/11/2021
ND, Input, pH	7.0	7.1	7.5	7.6
ND, Output, pH	5.5	6.2	5.1	6.7

Figure 51. pH analyser in ND



	6/30/2021	8/11/2021	9/28/2021	10/26/2021
SD, Input, pH	7.1	7.4	6.8	7.1
SD, Output, pH	6.0	5.3	5.7	5.5

Figure 52 pH analyser in SD

4.1.11 Soluble precipitation metal (Fe / Al)

This test is intended to clarify the situation with iron sulphide, which is added at the beginning of the purification cycle to cause the release of dissolved mineral pollutants. The task of monitoring is to understand what concentration of metals (Figure 53~~Figure 53~~, Figure 54~~Figure 54~~).

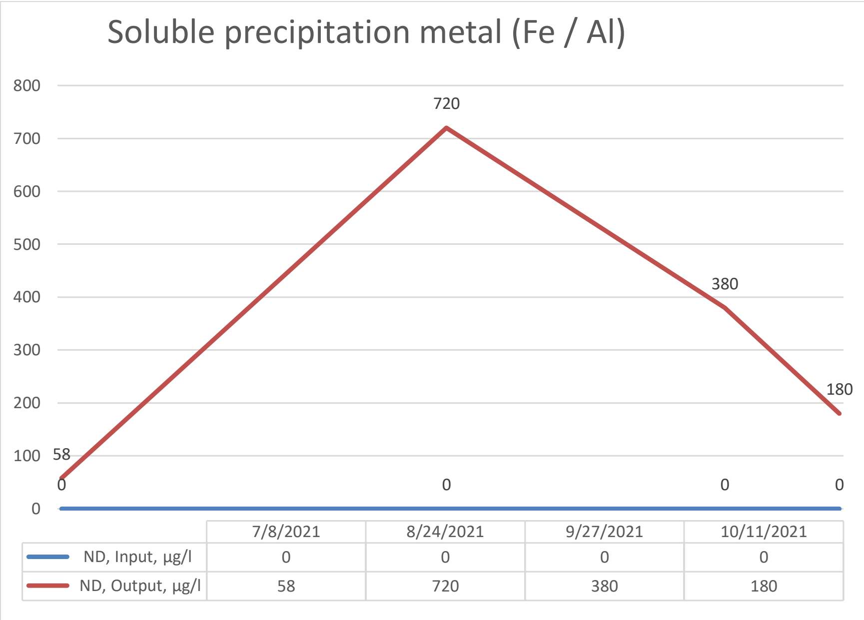


Figure 53. Results of soluble metal precipitation Fe in ND

In the process of analysis and sampling, Raita employees adjusted the volume of iron sulphide supply in the form of a special “RAKE iron chemical" tool.

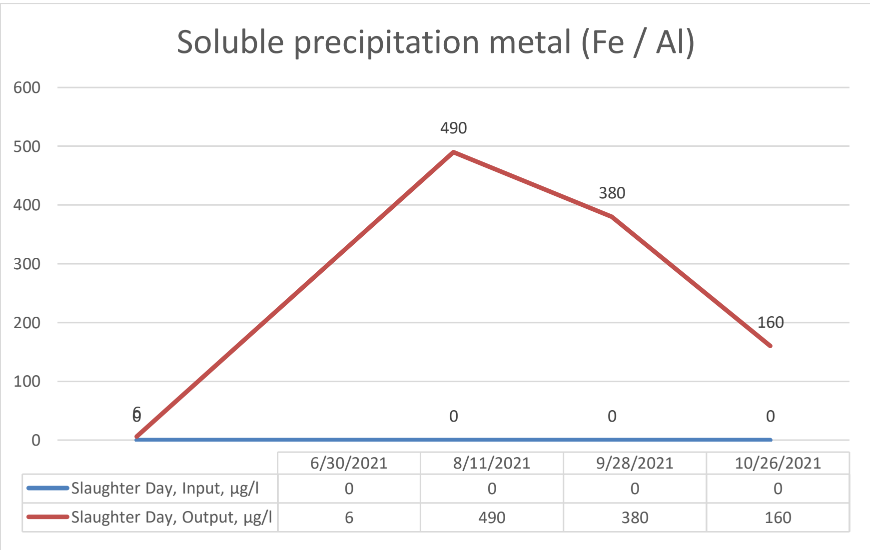


Figure 54. Results of soluble metal precipitation Fe in SD

It can be seen that the volume level of precipitated iron in the treated waters decreases after the peak value. This may indicate that the system is coming to a certain balance in operation and thereby reduces the load on the environment.

5 Discussion

As part of the modernization plan for the WWTP in Västankvarn, monitoring of the operation of a new WWTP was required. As part of the monitoring, investigations of wastewater samples were planned, organized and carried out. This lasted almost 5 months from June to October 2021, during which time the settings of the WWTP were changed. The supplier Raita Environment OY fine-tuned the delivery of coagulants and reagents. However, for the key parameters (BOD, phosphorus and nitrogen), results below the established thresholds have been obtained since the first laboratory test data were received. Achievement of research objectives

The aim of the work was to evaluate how well the new WWTP treats wastewater and removes Ptot, Ntot, solid contaminants, BO7, $NH_4 - N$ under slaughterhouse load and normal operation.

As shown above, the treatment plant was able to handle the load from the slaughterhouse and, of course, worked well on "normal" days. When we compare the wastewater coming to Västankvarn with the data given in (Finnish Water Utilities Association, 2018) for industrial wastewater, we can generally see differences. If the sample values in ND generally fit in the average range for similar wastewater. Then, the WWTP in SD experience double loading.

For example, as shown in the work of Wu (Ping Wu, January 2012), the pollutant load of wastewater in slaughterhouses can be regulated. And thus, achieve the best indicators of the efficiency of the treatment plant. Although WWTP currently cope with the task of effectively removing nitrogen, phosphorus, solids and other pollutants.

In general, the goal of the project was to evaluate the effectiveness of the new WWTP. To this end, samples of the incoming wastewater and the outgoing treated water were collected. The samples were taken to the laboratory, where they were analysed using certified methods. The obtained results were analysed, compared, visualised and described from the point of view of the processes taking place in the WWTP.

In general, it can be said that the WWTP copes well with the task of wastewater treatment. It withstands the load of wastewater from a polluted slaughterhouse and shows high efficiency.

5.1 Environmental impact of treatment wastewater

The decision-making at the management level of the Västankvarn farm manager, the approval of the renovation by the authorities of the Inkoo Municipality all led to a reduction in discharges. As can be seen from the study, the quality of wastewater purification from private households and from slaughterhouses is improving. This means that the impact, the load on the environment will be reduced in the long term.

Nutrients as nitrogen and phosphorus will be removed and will not enter the environment. To a lesser extent, the waters in the Inkoo municipality and in the Baltic Sea region as a whole will be negatively affected by eutrophication.

The work to save the Baltic Sea from anthropogenic impact, the consequences of eutrophication, and the reduction of biodiversity can be directly linked to similar actions to modernize treatment facilities.

At the same time, high-quality cleaning of solid particles, reducing the level of organic and chemical pollutants in the treated water thanks to new equipment will reduce the anthropogenic load on the local and regional water system.

Thus, legislation, management decisions and equipment modernization measures have a direct impact on improving the quality of the environment, reducing the burden on ecosystems, increasing business efficiency and improving the quality of life of local communities. As for example, it happened in Petrozavodsk (Modernization of sewage treatment plant in Petrozavodsk (Phase I), 2022), where, after the completion of the work, full compliance with Helcom requirements for the level of phosphorus in the release of treated wastewater was achieved.

5.2 Problems of research, improvement, development.

The main problems I have encountered can be divided into two groups. The first is the problems of planning and execution of the research. The second is problems with the use of threshold values.

The problems of planning and execution in the case of the study of WWTP consisted in uncertainty. The volume of wastewater is difficult to predict. It is possible to assume that in ND the volume and qualitative composition of wastewater is relatively stable. The number of residents is approximately constant, their behaviour and habits do not change dramatically. In the case of SD, the volume of wastewater and the presence of pollutants in them could vary depending on the duration of work, the type of preparation of livestock for slaughter, the number of animals. All this was difficult to consider and plan.

On the other hand, the mode of operation of treatment facilities and sampling in the afternoon and at night led to a delay in the collected samples before they got to the laboratory. How this delay affected the final result is unknown. However, there is an understanding that the bio-processes of decomposition of nutrients and trace elements in the wastewater in the samples begin almost immediately as the wastewater enters the sewer system.

The second group of problems was related to threshold values. As already noted, there are no strict standards for a number of analysed parameters (nitrogen, soluble precipitated Fe, COD). On the other hand, some thresholds prescribed in the legislation are softer than the standards in the permits issued by the authorities when approving an application for the modernization of treatment plant. For example, the requirements for threshold values of the content of phosphorus in treated wastewater.

6 Conclusions

As it was shown in this work, the renewal of treatment facilities leads to an improvement in wastewater treatment. For all key parameters - COD, BOD, phosphorus and nitrogen, the treatment showed compliance with standards and thresholds. This gives an understanding to all stakeholders that business development should be integrated with the development of the area. Special attention should be paid to the modernization and development of supporting and auxiliary services such as WWTP.

During the work, the flow rate in the sewage system as measured. With the help of a dye that is often used for similar purposes in the sewage system, we have obtained data that will be useful in the future to the management company Västankvarn Gard and other researchers and designers. Regulatory authorities can use this information to monitor and control the situation in order to maintain regulatory standards and preserve the health and safety of residents in the municipality, as well as the environment.

Moreover, the data collected during this work will probably be added to a series of long-term monitoring that will be carried out at the Västankvarn treatment plant. This will make it possible to make forecasts regarding the load on the treatment facility in the future. This study can help other farms and villages in Southwestern Finland to modernize and reconstruct sewage facilities and treatment facilities.

The results of the study are already being used by Raita Environment Oy (Oy Raita Environment Ltd, 2021) on its website as confirmation of the effectiveness of the «Raita BioKem XL system». The data from the study and the work on the thesis itself will be used to justify and confirm the effectiveness and expediency of investments in sales.

Since Västankvarn is a training field for students at Novia University of Applied Sciences, the results of the work may form the basis for the next development in the field of effective wastewater treatment in the future.

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