COASTLINE 2023-11
WEB

Technical preparation for wastewater treatment investments at BSR tourist destinations

K. Kuligowski & N. Effelsberg (eds.)

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Die Küsten Union Deutschland

Coastline Web

11 (2023)

Technical preparation for wastewater treatment investments at BSR tourist destinations

Editors:

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Rostock 2023

ISSN 2193-4177
ISBN 978-3-939206-31-6

This report was developed in the project NURSECOAST-II (Model Nutrients Reduction Solutions in Near-Coast Touristic Areas (2022-2025)). More information can be found on the project website: interreg-baltic.eu/project/nursecoast-ii-interreg-baltic-sea-region

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Danish Nature Fund, Denmark

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Association of Polish Communes Euroregion Baltic, Poland

EUCC - The Coastal Union Germany

VNK serviss, Latvia

Funding:

This project is funded by the Interreg Baltic Sea Region 2021-2027 programme and co-funded by the European Union.

Interreg Baltic Sea Region

Co-funded by the European Union

SUSTAINABLE WATERS NURSECOAST-II

Imprint

Cover pictures: Zviedris J., VNK serviss Ltd. (left, right: middle), Danmarks Naturfond (right: top, bottom)

EUCC-D

Coastline Web is published by:

EUCC – The Coastal Union Germany
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18119 Rostock, Germany
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Coastline Web is available online under www.eucc-d.de.

Preface

Wastewater (WW) discharged from near-coast Baltic Sea tourist destinations, often from very small treatment plants (TP) (<2000 Person Equivalent, PE), is characterized by a large variability of flow due to seasonality. Such conditions make it difficult to continuously obtain the required effluent quality parameters and may endanger the overall quality of the touristic place and satisfaction of clients. Finding different WW technological solutions that are especially adapted to tourist areas would reduce nutrient inputs to the sea across the BSR. The project NURSECOAST-II covers a broader approach than only technological solutions as the umbrella goal is to reduce the outflow of nutrients from touristic areas. It is possible that nutrient discharges are not being managed effectively at many tourist sites. The clear challenge is the adaptation to high seasonality. The project demonstrates the potential for a high macro-regional impact, as the challenge implies different solutions e.g. for sandy coasts of PL, DE, LT compared to rocky archipelagos of SE, FI, EE. The novel approach of NURSECOAST-II examines different aspects of the water value chain that have been identified as being gaps and problematic areas: WW treatment technologies, treated WW reuse, using nature to treat the excess of WW in the summer, greywater and sludge management, replication, and reintroduction. The main benefitting target groups are local public authorities and touristic site owners and operators.

This report describes the technical solutions for 5 pilot wastewater treatment plants being studied during the NURSECOAST-II project. They are located in Latvia (2 pilots, only 1 described), Finland (1 pilot), Denmark (2 pilots) and Poland (1 pilot).

The solutions are built around technologies such as constructed wetlands, nanobubbles aeration, wastewater reuse for irrigation, and water reduction aspects. These basic technologies were chosen as the most appropriate for touristic areas affected by seasonality.

Together the assessments presented in this report form a basis of discussion and decision making for local authorities and site managers on how wastewater can be handled best in touristic areas that are vulnerable to nutrient pollution due to seasonality. This is backed up by the concrete pilot installations in 4 countries. The work of NURSECOAST-II on wastewater treatment in tourist areas is crucial to address the challenges posed by the expected increasing numbers of visitors to the Baltic Sea coast. It ensures the sustainability of the region’s tourism, protects the environment, promotes public health, and contributes to the overall positive experience of both residents and tourists.

Ksawery Kuligowski (Institute of Fluid-Flow Machinery Polish Academy of Sciences)

Location of the pilot wastewater treatment plants in the NURSECOAST-II project (map: Grupa Projektowa ZOOM).

Content

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Pilot 1: Optimising the pollution capacity of the biological wastewater treatment plant in the village of Jūrkalne, Latvia

Diana Skudra & Janis Zviedris

VNK serviss Ltd.

Abstract

The village of Jūrkalne is one of the most visited tourist destinations in Latvia due to its geographical location by the Baltic Sea and beautiful natural views. During the tourist season, it is difficult to predict the nature of untreated sewage pollution in the wastewater treatment plants in Jūrkalne village, which is typically higher than in other seasons. For these facilities to successfully meet the environmental requirements during the tourist season, a lot of effort and planning is currently required for short-term capacity expansion solutions, which are not rational in the long term. It is therefore necessary to find compact and easy-to-maintain solutions so that wastewater treatment can be carried out during the tourist season in a simple way and in a way that does not increase operating costs in the long term.

1 Pilot Site Description

The pilot site is located in the village of Jūrkalne, Ventspils Municipality (Fig. 1). Jūrkalne is located on the Baltic Sea coast and has the highest coastal steep shores in Latvia, visited by many tourists and visitors during the tourist season. This creates seasonal problems in wastewater treatment due to changing pollution levels and the inflow of wastewater into the Jūrkalne wastewater treatment plant.

Figure 1: Pilot location in Latvia (map: Grupa Projektowa ZOOM).

Jūrkalne WWTP provides centralised wastewater treatment for about 150 permanent residents on a daily basis.

At the same time, the length of the tourist season and the number of tourists in the village depend on weather conditions and global happenings. It is therefore difficult to predict the average tourist season each year. In Jūrkalne there are also residential and guest houses which are not connected to the centralised sewerage system, as this is not technically and economically feasible. For this reason, some of the households and guest houses use decentralised sewerage systems, the contents of which are periodically pumped and transported to the Jūrkalne wastewater treatment plant, which is also a difficult volume to predict.

Figure 2: Jūrkalne steep bank and the beach, which is actively visited by tourists during the tourist season (photos: Zviedris J., VNK serviss Ltd.).

During the active tourist season, most of the problems are related to changes in pollutant loads, which make the capacity of existing wastewater treatment plants insufficient. Therefore, a decision has to be taken on how to optimise the wastewater treatment processes so that their capacity does not have to be increased according to the pollutant loads.

Considering that according to the conditions of the permit issued by the State Environmental Service, wastewater monitoring in Jūrkalne village must be carried out once a quarter, i.e. 4 times a year. The following data charts (figures 3 to 8) show the trend of increasing concentrations of pollutants during the tourist season. In order to determine more accurate pollution dynamics in untreated wastewater, testing of wastewater should be more frequent, at least once a week, which is planned to be done as part of the pilot.

The increased concentration of total nitrogen in untreated wastewater in March 2022 is most likely related to the unauthorised discharge of the contents of decentralised sewerage systems into centralised sewerage networks (such cases do occur and the VNK serviss works on this issue daily to eliminate such cases in the future), which reaches the wastewater treatment plants in dissolved form. However, there are uncertainties here, as the concentrations of COD and BOD5 should be elevated along with the concentrations of total nitrogen. As mentioned above, VNK serviss plans to carry out more frequent monitoring of wastewater during the project (mandatory monitoring should be carried out once a quarter) to obtain more data on the dynamics of daily pollution changes and their sources.

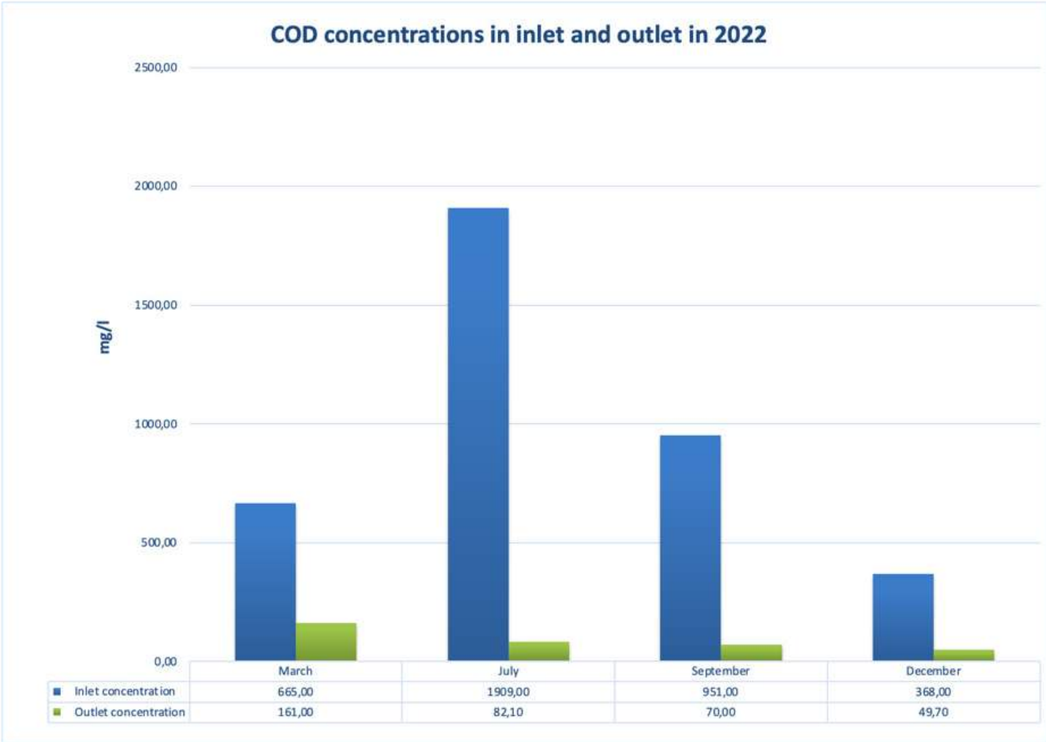

Figure 3: Variation of COD concentrations in untreated wastewater in 2022 (Zviedris J., VNK serviss Ltd.).

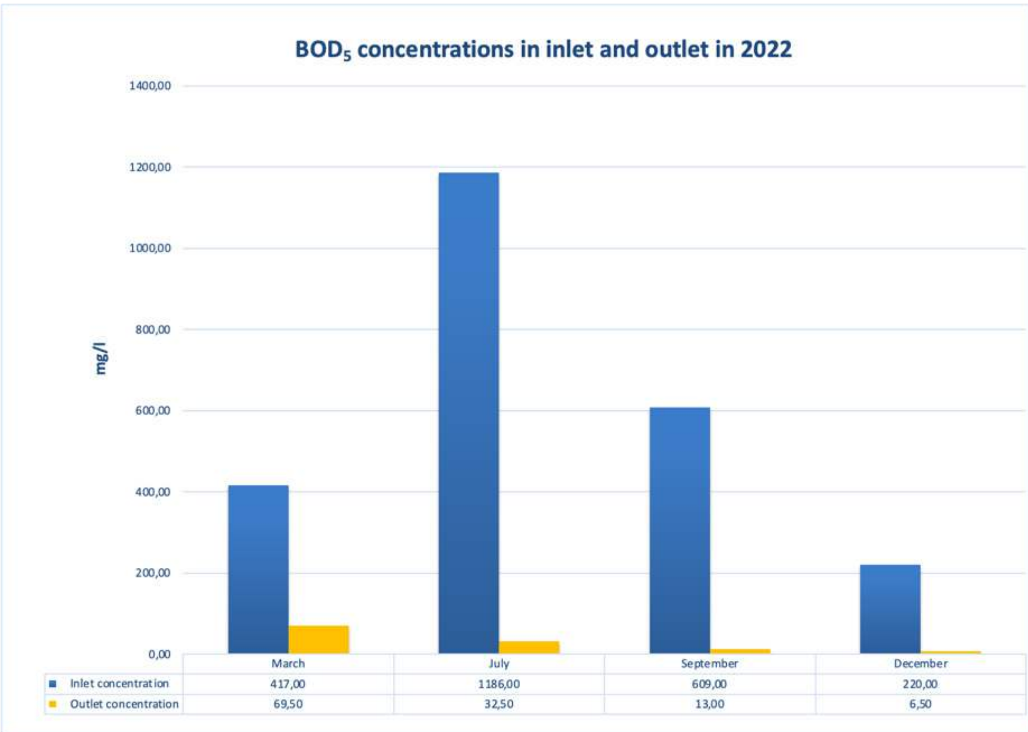

Figure 4: Variation of BOD_5 concentrations in untreated wastewater in 2022 (Zviedris J., VNK serviss Ltd.).

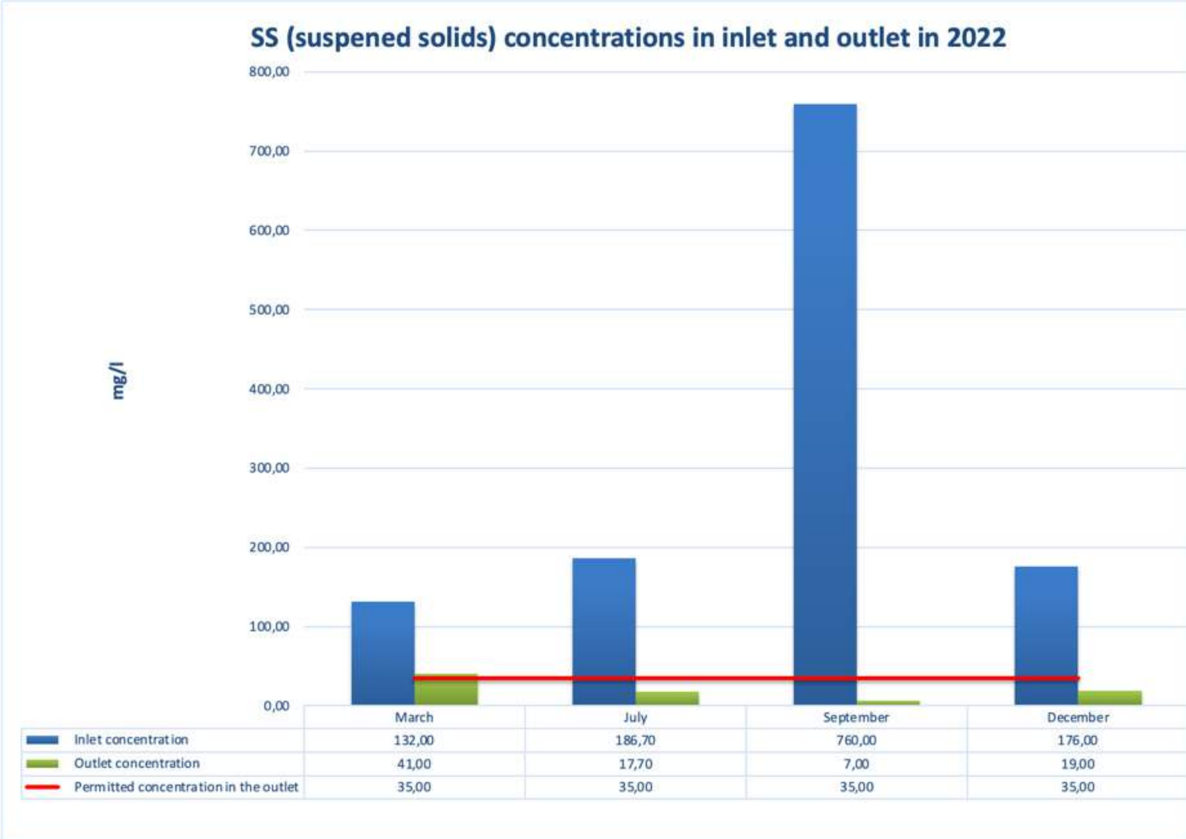

Figure 5: Variation of SS concentrations in untreated wastewater in 2022 (Zviedris J., VNK serviss Ltd.).

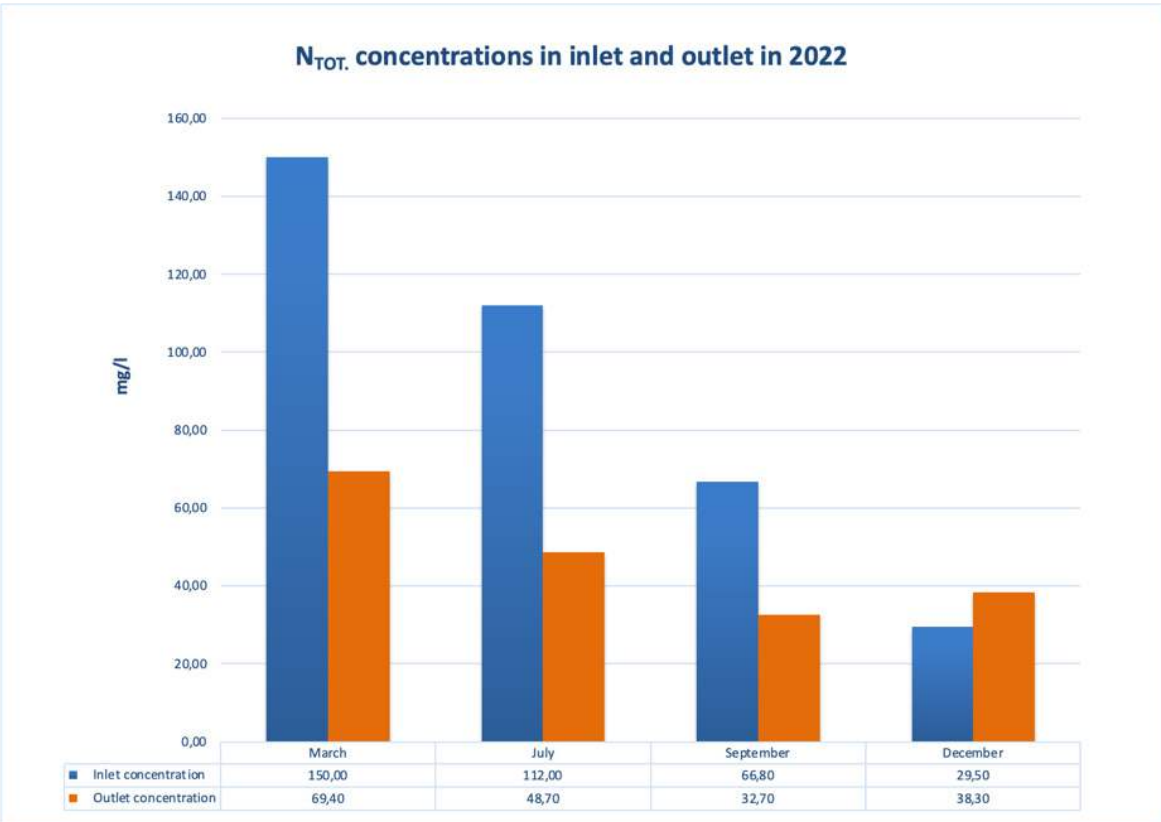

Figure 6: Variation of total nitrogen concentrations in untreated wastewater in 2022 (Zviedris J., VNK serviss Ltd.).

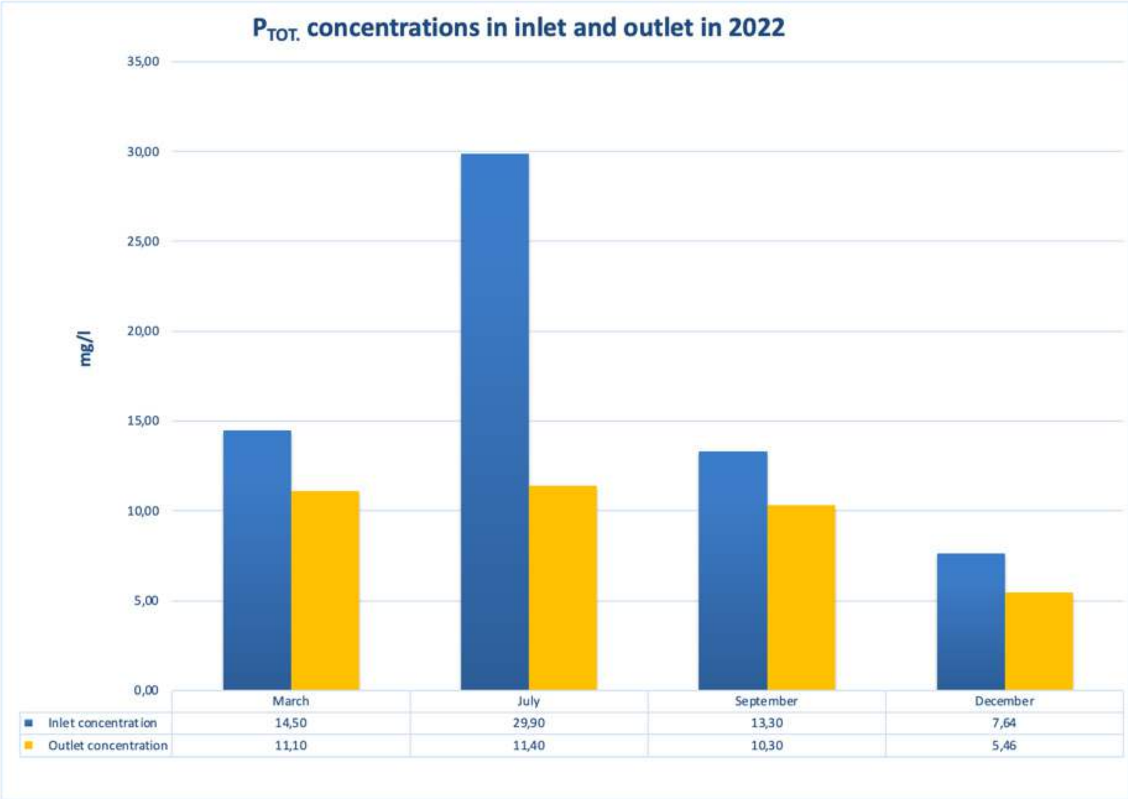

Figure 7: Variation of total phosphorous concentrations in untreated wastewater in 2022 (Zviedris J., VNK serviss Ltd.).

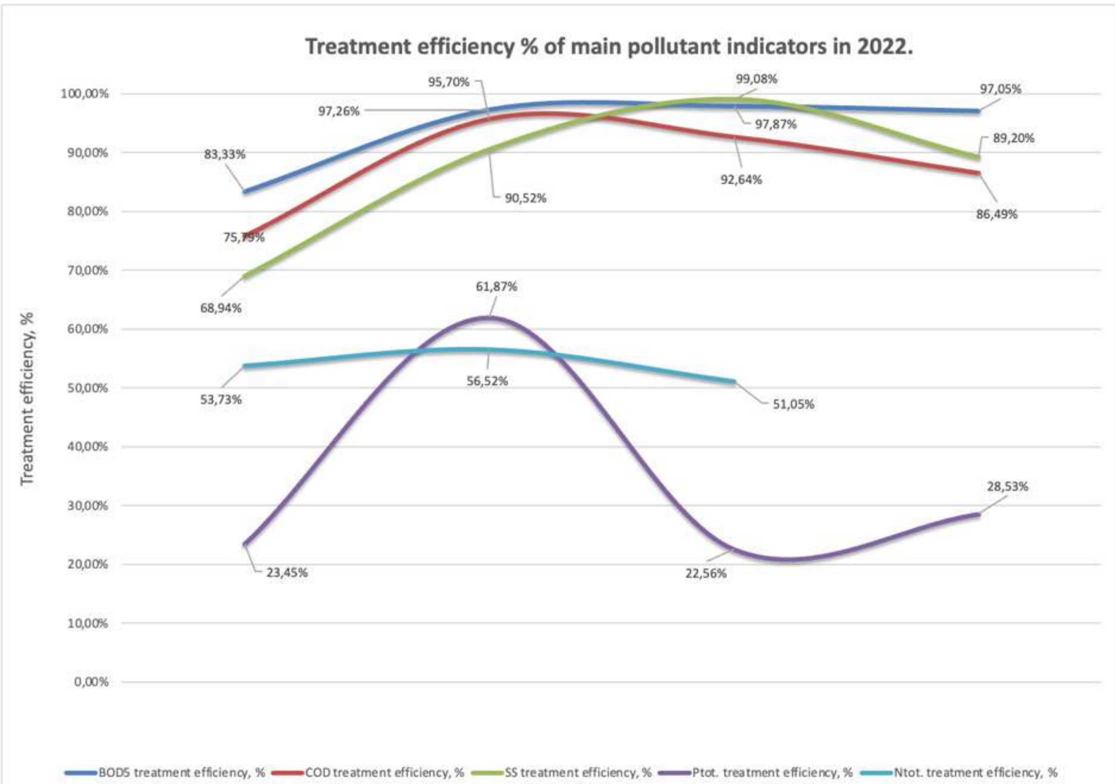

Figure 8: Variation of treatment efficiency in 2022 (Zviedris J., VNK serviss Ltd.).

According to the pollution permit issued by the State Environmental Service of Latvia, the following polluting substances must be treated and monitored at least once a quarter at the Jūrkalne wastewater treatment plant (Tab. 1).

Table 1: Pollution permit limit value conditions for the operation of the wastewater treatment plant in Jūrkalne.

Polluting substance	Maximum concentration of pollutants, mg/l	Percentage of pollution reduction
Suspended solids	<35	90%
BOD_5	N/A	50-70%
COD	N/A	50-70%
Total nitrogen	N/A	Appropriate treatment
Total phosphorous	N/A	Appropriate treatment

Although the current environmental protection requirements do not require nitrogen and phosphorus treatment of small wastewater amounts, considering that the wastewater treated at the Jūrkalne WWTP flows into the Baltic Sea, the VNK serviss Ltd. focuses its activities on the treatment of nitrogen and phosphorus compounds as well, reducing the eutrophication impact of the Baltic Sea.

2 Information on technology

Industrially manufactured biological wastewater treatment plant BIO M-30 was built in 2015, completely replacing the old wastewater treatment plant, which was both morally and physically degraded. In table 2 all main design characteristics for biological wastewater treatment plant BIO M-30 are reflected.

Table 2: Designed input data of BIO M-30 wastewater treatment plant.

No.	Description	Unit	Amount	Notes
1	Capacity	m^3/d	up to 30	
2	Flow:			
	min	m^3/h	0,75	
	max	m^3/h	2,0	
	COD	mg/l	210 - 740	Inlet
6	BOD_5	mg/l	150 - 350	Inlet
7	BOD_5 / COD		0,5 – 0,7	Inlet
8	Suspended solids	mg/l	120 - 450	Inlet
9	$N_{TOT.}$	mg/l	20 - 80	Inlet
10	$P_{TOT.}$	mg/l	6 - 23	Inlet
11	pH		6,5 – 7,5	Inlet
12	Temperature	^0C	11 - 25	Inlet

Designed efficiency				
13	COD	mg/l / %	<125	Outlet
14	BOD5	mg/l / %	<25	Outlet
15	Suspended solids	mg/l / %	<35 / 90	Outlet
16	NTOT.	mg/l / %	N/A / 60	Outlet
17	PTOT.	mg/l / %	N/A / 50	Outlet
Installed electric capacity				
18	Total	kW	1,12	
	Air blower	kW	0,75	
	Pump - mixer	kW	0,37	
Electricity consumption				
19		kWh/d	16,6	
20	Operating staff	man	1	
21	Normative service time	h/d	1	

In order to understand more precisely how the wastewater treatment plant in Jūrkalne was constructed, figure 9 shows a cross-section and plan of the constructed biological wastewater treatment plant BIO M-30.

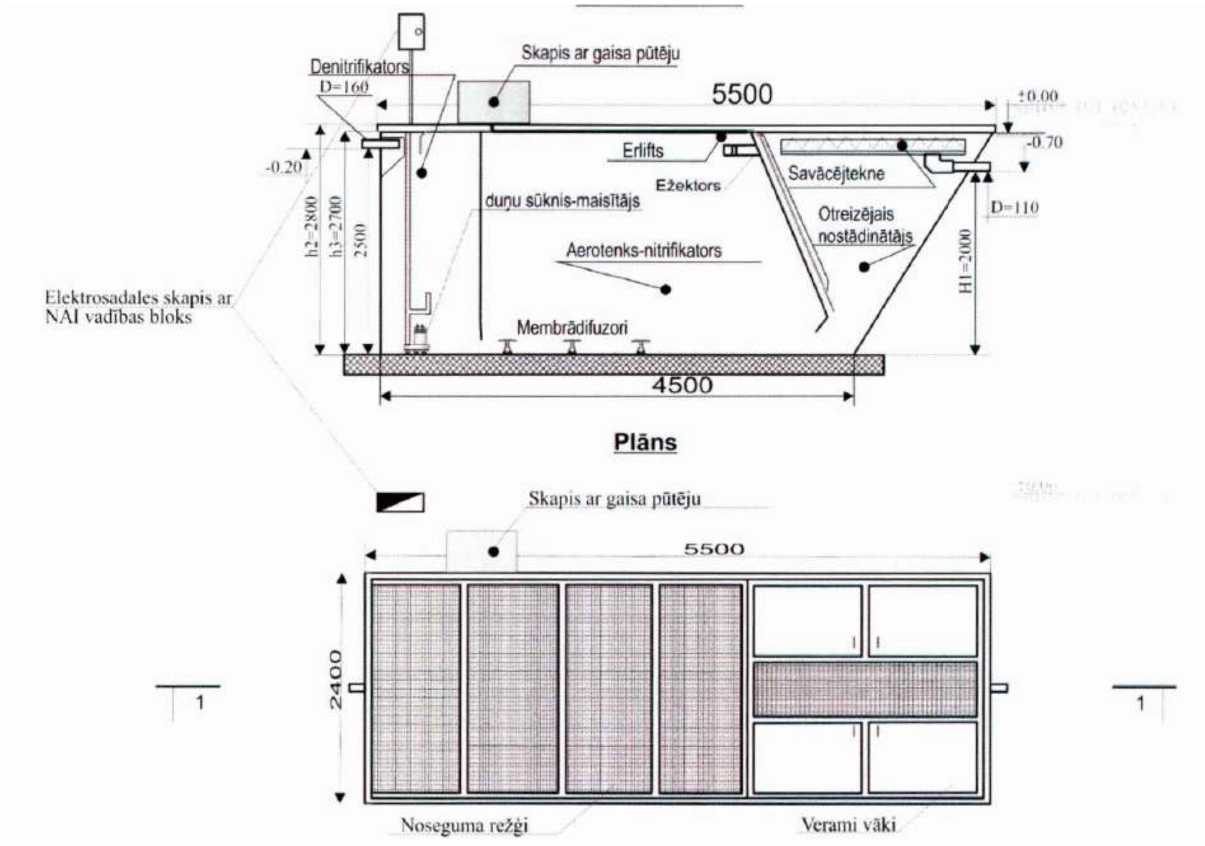

Figure 9: As built drawings of the biological wastewater treatment plant BIO M-30 (Kombi D Ltd.).

Figure 10: Pictures of biological wastewater treatment plant BIO M-30 (photos: Zviedris J., VNK serviss Ltd.).

Pre-treatment of the raw wastewater (sand, some grease, other fast sinking, or floating impurities) takes place in a primary clarifier made of reinforced concrete elements with D = 1500 mm, H = 2.8 m. Settling time 2,8 hours at average daily flow.

After mechanical pre-treatment, the effluent flows into the anaerobic (denitrification) zone of the biological treatment reactor. At the same time, activated sludge from the secondary settling tank is pumped into the denitrification zone by means of an airlift. A pump-mixer is installed in the denitrification zone to produce a homogeneous mixture of the incoming effluent and activated sludge before it enters the next biological wastewater treatment zone. The pump-mixer is set to operate in hourly mode: 15 minutes running, 45 minutes not running.

From the denitrification zone, the mixture of wastewater and activated sludge flows through openings in the bulkhead into the aerobic part of the aeration tank (nitrification zone), which is equipped with an aeration system with stainless steel air manifold and membrane aerators with D=300, air inlets made of reinforced plastic pipes and shut-off valves. The aeration system is supplied with air from a blower installed next to the biological wastewater treatment unit in a stainless-steel cabinet. The electrical cabinet with the control unit for the wastewater treatment plant is located next to it.

The following processes are carried out in the aerobic zone: nitrification, reduction of BOD5 and COD, activated sludge regeneration. Throughout the biological wastewater treatment cycle, a residual dissolved oxygen concentration of 2,5-4,0 mg/l and an activated sludge concentration of 2-4 g/l are maintained. After the aerobic zone, the mixture of wastewater and activated sludge flows into the secondary clarifier.

The settling part of the secondary clarifier has sloping walls where the activated sludge settles out, while the upper part collects treated effluent which flows out of the WWTP into a control well via an adjustable toothed weir. The activated sludge settled from the lower part of the secondary clarifier is returned to the anaerobic (denitrification zone) of the biological wastewater treatment plant by means of an airlift. The airlift is powered by air from an air blower.

The air supply to the biological wastewater treatment process is controlled to produce a flow of wastewater towards the secondary settling tank, with the flow returning against the inclined wall of the clarifier and forming a coil.

This flow makes it possible to return the floated sludge from the upper water layer of the secondary clarifier back to the aeration tank through ejectors installed in the wall, and to draw back from the aeration tank part of the settled sludge from the bottom of secondary clarifier.

A mineralizer has been created for sludge storage and mineralization, i.e. separate tank buried in the ground (reinforced concrete element well with D=1500mm, H=2.8 m). Impurities collected during the maintenance of the equipment can be stored in it, and excess sludge (if more than 50% of the volume) and sediments from any area of the treatment process can be pumped to a mobile sewage pump. The mains pump can be connected to a single-phase socket, which is installed in the electrical distribution cabinet with the WWTP control unit. When the Jūrkalne WWTP was built, the equipment supplier was required to provide certain guarantees, which are summarized in table 3.

Table 3: Warranties of the WWWTP after taking in operation.

Name of equipment		Warranty time
1	Stainless steel aeration tank, air duct, airlift, wastewater chute, bulkhead covers	20 years
2	Cover grates made of galvanized metal	20 years
3	Aeration system – membrane diffusers, reinforced plastic pipes and shut-off valves	36 months
4	Air blower	24 months
5	Pump - mixer	24 months
6	Portable sewage pump	24 months
7	Stainless-steel cabinet for air blower	20 years
8	WWTP controlling unit	36 months

3 Planning the investment

The wastewater treatment plant, in which investments are planned, has been handed over to VNK service under a long-term contract between VNK serviss Ltd. and the municipality of Ventspils region. Before making investments, it will be necessary either to invest wastewater treatment equipment in the capital of VNK serviss Ltd. or to confirm long-term use rights in the Land Registry of the Republic of Latvia.

The pilot plant is planning to use a nanobubble solution from TECHRAS NANO ApS in the biological part of the wastewater treatment, potentially allowing the wastewater treatment plant to be scaled down current size and more efficiently delivering dissolved oxygen to the micro-organisms that treat the polluting nutrients. This is particularly important with changing pollutant loads in untreated wastewater during tourist seasons. The general input data for pilot calculations are assumed from worst case scenario with max inlet flow 2 m^3/h and max inlet COD concentration1900 mg/l.

Expected KPI's:

- Meet the requirements of 35mg/l TSS in effluent water;
- Odor reduction;
- Improvement alpha factor;
- Higher DO values in the aeration tank, based on the assumption that the plant has been unable to hold DO values high enough up during the piloting:
- Improvement in secondary sludge settleability.
- Improved effluent quality (reduction of COD, BOD and TSS values).

Installation of the project equipment is planned for the first half of 2024.

The project equipment Supplier will be responsible for delivery of equipment and for installation of the equipment in accordance with equipment's installation specification. The Supplier shall ensure that the works covered by the contract are performed and managed by persons with appropriate professional qualifications.

The investment works will be paid for 80% from the project, 20% will be the costs incurred by the Ordering Party.

Table 4: System boundaries to test nano bubble technology in wastewater treatment.

Treatment efficiency vs Legislation	Increase capacity of the existing WWTP and increase the nutrient removal ensuring appropriate treatment (<2000 PE)
Energy Consumption	Comparison to conventional bottom aeration system
Cost-Effectiveness	Equipment, maintenance, and operational costs compared to conventional treatment methods
Scaling Up	Seasonal variation - 100 PE to 500 PE or even more (WWTP is designed for 175 PE)
Other concerns/ requirements	Optimization of current WWTP process to be capable to catch and treat seasonal fluctuations of wastewater flow and pollution load in worst case scenario

4 Management

The company VNK serviss Ltd.has the following resources at its disposal:

- The existing wastewater treatment plant where a solution could be developed. Moreover, there is an access road leading to this area of land. There is an electricity supply, and it is possible to access running water near the wastewater treatment plant;
- human resources are three people employed on the project on a part-time basis for project management, administration, communication, promotion and finance, and on-site control of the WWTP.

Installation of equipment in WWTPs, wastewater monitoring and controlling will be the task of VNK serviss Ltd.

5 Social impact

The project aims to address sewage pollution challenges in Jūrkalne village, a popular tourist spot in Latvia. The social impact will be significant as it seeks to ensure effective wastewater treatment during the tourist season, reducing environmental risks and avoiding the need for costly short-term solutions. This will contribute to a cleaner and more sustainable environment, benefiting both residents and visitors in the long term.

6 Local legal framework

The VNK serviss Ltd. is responsible for the entire implementation of the pilot investment and investments are planned together with the annual company's budget.

The Supplier will be responsible for the delivery and installation of requested equipment.

The Supplier will be selected as a result of the procedure of the procurement procedure established by the legislation of the Republic of Latvia, which will be evaluated by an independent procurement commission in the company. This procedure has been established by the VNK serviss Ltd. shareholder, the Venstpils County Municipality.

7 Activity

Taking into account that VNK serviss Ltd has been operating the wastewater treatment plant in Jūrkalne village for a relatively short time (since June 2021) and analysing the information available so far, which can be considered reliable, further activities to improve the existing wastewater process are based on the worst case scenario observed so far, assuming that the maximum wastewater flow could reach 2 m^3/h and the COD load could peak during the tourist season up to 1900 mg/l.

8 Outlook

Solving the issue of pollution capacity during the tourist season, it is expected that:

- the treatment efficiency of biodegradable organic pollutants will improve;
- the growth of excess biological sludge will decrease;
- there will be opportunities to evaluate the reduction of operating costs of wastewater treatment plants in the long term;
- there will be more accurate information about the effect of the nanobubble aeration system on the biological wastewater treatment process.

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Cabinet Regulation No. 34, adopted 22.01.2002, Regulations Regarding Discharge of Polluting Substances into Water with amendments from 04.04.2023.

Jūrkalne wastewater treatment plant test reports, 2022

Pollution permit issued by the Latvian State Environmental Service, 2015

Acknowledgement

The work has been carried out within the project NURSECOAST II, funded by the Interreg Baltic Sea Region Programme and co-funded by the European Union.

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K. Kuligowski & N. Effelsberg (eds.)
Technical preparation for wastewater treatment investments at BSR tourist destinations
***Coastline Web 11 (2023)**, ISSN 2193-4177, ISBN 978-3-939206-31-6*
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Pilot 2: Renovation of the Barösund wastewater treatment plant in the municipality of Ingå, Finland

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Abstract

During the high season, the amount of wastewater handled by the Barösund marina's water supply exceeds the capacity of the local small-scale treatment plant. For this reason, solutions have been sought both in terms of saving water and increasing the cleaning capacity. The problem is caused by the high load during the tourist season and on the other hand the too low utilization rate outside the tourist season. Such conditions usually make it difficult to meet the requirements set for conventional cleaning processes and cause an extra load on the area's environment and the Baltic Sea. The novel small-scale treatment plants using new technology should meet the environmental, social, and economic criteria supporting local applicability and cost effectively guarantee effective nitrogen and phosphorus removal properties. Three small-scale wastewater treatment plant options have been offered for the Barösund area.

1 Pilot Site Description

Bärosund marina is in the Bärosund strait in Ingå, between the islands of Barölandet and Orslandet. Ingå is located on the coast of southern Finland on the shores of the Baltic Sea. The activity in the harbour area is mainly in the summer during the boating season. One can get to the marina by car across the strait at the port. The port area and its functions have been developed over the past few years and the area will be further developed. As a result, the capacity of the current wastewater system has become small during the high season. In the surroundings of the Bärosund harbour area, there is a shop, a cafe, a restaurant, a service building, a clubhouse, a boat pier, as well as accommodation, a padel court, and meeting activities (Fig. 1).

Barösund water cooperative's wastewater is treated in its small-scale treatment plant, which was completed in 2005 (Wehoputs 30). Eleven properties have joined the Barösund water cooperative's water supply, four of which are in year-round use (about 20 residents). As the owner of the old school property Scola, the municipality is the largest shareholder of the water cooperative. The challenge of the cooperative's operation is the uneven load, which is strongly concentrated in the summertime. During the summer, 100-200 tourists visit the area every day. The amount of wastewater generated during the tourist season exceeds the capacity of the treatment plant, so the water has been led to a holding tank and transported from there for further treatment. The area's water use is about 1,000 m^3 per year, but the monthly variation is large and most of the water use is in the summertime.

Figure 1: Bärosund marina and Scola Restaurant (photos: Johan Holmberg).

Insufficient WWTS may cause wastewater overspill and risk to groundwater and surface water. As the Baltic Sea is already one of the most polluted seas on the globe with eutrophication (Heiskanen et al. 2019, Kahru et al. 2020, HELCOM 2022). The root cause used to be untreated industrial and household wastewaters, nowadays the main reason is agriculture (Cederqvist et al. 2020). However, it is important to reduce environmental pressure in any possible manner as the scattered settlements are also one source for nutrient loads.

2 Information on current systems technology

A WehoPuts 30 (capacity 4,5 m^3/d) biological chemical small-scale treatment plant has been installed for the water treatment of the Barösund harbour area, which works on the batch principle. WehoPuts 30 is intended, for example, for the treatment of wastewater from village schools, holiday homes, dairy farms, and small factories. The WehoPuts treatment plant consists of a ground-mounted tank, which includes a storage tank part and a process part, and the equipment belonging to the treatment plant. Phosphorus is chemically removed with a precipitation chemical, the dosing of which is the responsibility of the user.

The size of the equalization tank is 30 m^3, which is mostly sufficient for the current water volumes. From time to time, it has been observed in the area that the tank is overflowing, which causes possible odour nuisance, harm to the comfort of the area, and, most importantly, the risk of contamination of domestic water wells. The tank has been emptied 3-8 times a month during the summer 2020 season. The tank truck can take about 14-15 m^3 of wastewater at one time. As the amount of water increases, so does the need to empty the tank. The treatment plant can process 5 m^3 of wastewater per day (PE 30).

Technical data of WehoPuts 30 (Uponor, Finland, Fig. 2) treatment plant is following: it is biological-chemical batch reactor for year-round use to treat all household wastewater and includes microbiological degradation, chemical fixation of P and sedimentation. The expected lifespan of this wastewater treatment system is 50 years.

Figure 2: WehoPuts 30 (photo: Uponor).

Treatment process

The WehoPuts treatment plant works on a batching principle SBR (Sequenced Batch Reactor), treating a certain batch of wastewater at one time. The treatment is based on a biochemical process, where the microbes living in the activated sludge decompose the organic matter in wastewater, while the chemical deposits the phosphorus.

The cleaning process is divided into different stages: aerating, chemical feed, settling, and removal. These stages are carried out in sequence inside the process tank. Control of these stages is carried out automatically through the control unit. After an electrical outage, for example, the treatment plant will automatically resume the process from the interrupted stage.

Wastewater batch accumulation

Wastewater is directed into the storage tank without separate pre-treatment. From the storage tank, the wastewater is pumped into the process tank. Once the wastewater level in the process tank reaches the start-up level, the process starts.

Aerating and chemical feed

The compressor in the machine room aerates the wastewater. Aerating promotes biological decomposition and the oxidation of nitrogen compounds into nitrate. At the end of the aerating phase, a chemical is added to the wastewater. Phosphorus compounds are separated from the wastewater using the chemical.

Nitrogen removal and settling

Aerating is stopped and sludge slowly settles to the bottom of the process tank. The treated, nutrient-free water gathers on top. The nitrate-form nitrogen is reduced to nitrogen gas.

Removal of treated water and residue sludge treatment

After settling, the treated water is then discharged. Residue sludge is regularly transferred to the sludge bag. Sludge may be composted with other organic household waste. Alternatively, it can be removed using a vacuum truck.

Water quantities

Barösund water cooperative takes water from its well. Water consumption is about 1,000 m^3 per year. The largest user in the area is the marina and water use is focused on summertime (June-August). The water consumption data for the years 2019 and 2022 are described in figure 3. Part of the water consumption goes to filling the water tanks of the boats, as well as the water tanks of summer cottages, and thus does not burden the wastewater treatment plant. Water consumption in the summertime exceeds the capacity of the wastewater treatment plant during the summer months, even though some of the water is not returned to the wastewater treatment plant. The highest water use is on weekends when water is consumed well beyond the capacity of the current wastewater treatment plant. In the area, the biggest water consumers have been a restaurant, a shop, an accommodation building, and a service building where toilets and washing facilities are available for visitors.

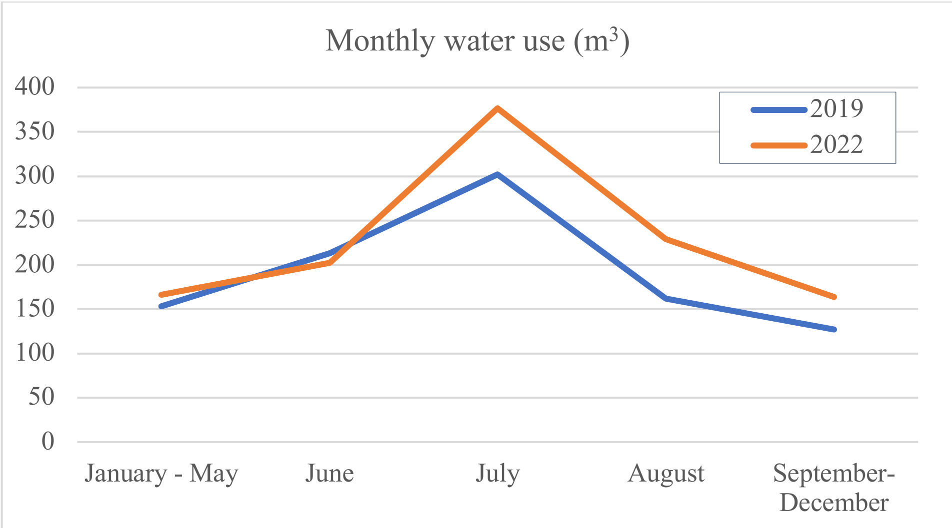

Figure 3: Water use in 2020 and 2022 (Municipality of Ingå 2023).

The seasonal water use of the Barösund marina and the correspondingly variable amount of wastewater present challenges for wastewater treatment. In terms of the area's development, quality, and securing its domestic water supply, wastewater treatment must be controlled and under no circumstances should wastewater enter the terrain directly. According to the water samples taken in the summer of 2023, the special feature of the wastewater generated from the operation is a significant proportion of back water. This brings challenges but can be managed with technical solutions. For this reason, it may not be economically viable to adapt to the seasonal variation with the originally planned separate treatment of greywater. In addition, the purpose of sufficient wastewater treatment capacity is to ensure that wastewater does not end up directly to the Baltic Sea increasing the eutrophic load, which is a problem in coastal areas in Finland.

3 Planning the investment

Since the amount of wastewater generated in the area has exceeded the capacity of the old wastewater treatment plant, it is necessary to replace the entire treatment plant with a larger one. In addition, the new wastewater system must be able to function well in fluctuating seasonal loads. The cleaning result required from the system must take into account the requirements of the legislation and the regulations of the municipality.

In Finland for treating domestic wastewater outside sewer networks according to the EU Water Framework Directive, the Council of State issued the Environmental Protection Act (527/2014), the amendment (19/2017) concerning the treatment of wastewater from areas with dispersed settlement, and supplementary for that the regulation for household wastewater treatment outside areas of sewage networks (157/2017). According to these regulations technological neutrality applies to choosing a method of treatment. The owner must choose a method that will meet the requirements. As for the general treatment specifications, it is required that all onsite owners must fulfil the requirement of removing from influent a minimum of 80 % of organic matter, at least 70 % of the total phosphorus, and at least 30 % of total nitrogen. In Finnish legislation, acts and decrees are equally binding. The municipality has the right for setting higher requirements for sensitive areas. All onsite owners are obliged to be aware and to make a clarification of their wastewater system so that an estimation of the load of the system for the environment can be made. The owner is also obliged to monitor the functioning of its system, and if needed, to show that the system meets the demands set in the regulation. Before starting a wastewater renovation an operation permit must be applied from the municipality. A wastewater plan is an obligatory appendix to the application. The municipality is responsible for the safety handling of the sludge born at onsite treatment systems.

Ingå municipality's instructions for households

The wastewater treatment method is not specified in the regulation, but it is determined according to the amount of wastewater, the load, and the surrounding conditions during the planning phase. The municipality of Ingå has prepared recommendations for the selection of a wastewater system outside the area of the water supply plant. When choosing the system, the characteristics of the area must be considered (soil, groundwater areas, coastal areas, general plan regulations). A professional designer must be used in the design of the wastewater system.

Closed tanks cannot be considered a sustainable wastewater treatment solution. Low-water WC systems or compost toilets should be preferred in sparsely populated areas. Separation of grey water (washing water) and toilet water is recommended. Further, all wastewaters can be treated without separation in a biological-chemical small-scale wastewater treatment plant. The construction of a small treatment plant requires a maintenance contract and regular monitoring of the cleaning power and operation, including sampling. Treated wastewater must not be discharged directly into a watercourse or a ditch leading to a watercourse. Treated wastewater must be absorbed into the ground or e.g. a wetland.

The current system is owned by a water cooperative and municipality of Ingå is a member of it. Based on the results of the wastewater samples taken in summer 2023, the treatment plant does not meet the requirements set for the treatment of wastewater from scattered settlements. Based on the wastewater samples taken, the treatment plant needs an environmental permit. Due to the changed situation, the division of responsibilities must be clarified; the environmental permit it is no longer a one-off cost, but a permanent responsibility for the monitoring and operation of the system, sampling, etc. The municipality has clauses in its lease agreement regarding the Scola building, whereby the tenant is responsible for the permits and systems required for their operations. Further, municipality must now negotiate with the entrepreneur about the changed situation and ensure that the water cooperative will accept this rather significant change which will postpone the implementation of the project.

4 Management

The municipality of Ingå has commissioned preliminary studies on the need for modifications, organized a market dialogue, will organize a tender process and order the final wastewater plan from an external consultant. The purpose of the market dialogue is to make extensive use of information available on the market, which the purchasing unit can use when planning the purchase. The aim of the dialogue is to get information about the small-scale cleaning plants on the market that are best suited for the purpose and to evaluate the differences between the offered solutions and their comparability. The information obtained from the market dialogue is used in the preparation of the tender request. Furthermore, official investigations and documentation of the actions will be done by Ingå municipality. Legal requirements, technical aspects, purification efficiency, cost, quality, schedule, monitoring, management concerning the new system will be studied. Ramboll Finland Oy, commissioned by the municipality of Ingå, has investigated the water supply of the Bärosund marina development opportunities. Moreover, international evaluation of the Ingå pilot was organized by the Nursecoast-II project. This peer-to-peer report (06/2023) offers expert opinion and feedback on the project's pilot investments in terms of selecting the most effective and optimal technological solution to serve the local community. It is also intended to be a guidance of good practices showing the different aspects of selecting the optimal solution based on known and proven technologies (the best on the market).

5 Social impact

Regarding the sludge management, the municipality of Ingå has organized together with Scola's entrepreneur the emptying of the sludge and grease pit. Scola's entrepreneur has used his own time to maintain the device and take care of the water cooperative's affairs. In addition, Scola's entrepreneur has been personally responsible for the operation of the equipment.

The ecological surroundings of the pilot area are rocky and in places clayey, which will challenge and affect to the construction work. The current system causes odour nuisance to the local people (customers, workers, residents). The new system is designed to be built further away from the Scola guest marina area to resolve mentioned challenges.

The wastewater treatment system (WWTS) is co operational system, meaning that residents and the restaurant entrepreneur jointly are partners, owning and maintaining WWTS together. This is beneficial to all as the costs can be shared as well as the responsibilities. However, problems arise when one member loads the wastewater network more than others, which has also led to misunderstandings with the municipality of Ingå, the entrepreneur and other members of the water cooperative. These discrepancies are still under investigation.

Even though in Finland it is possible to use the wastewater sludge in agriculture or to fertilize green areas, the opportunities to reuse wastewater (e.g. reuse nitrogen and phosphorus or utilize water in irrigation) in the pilot case are poor, as there are no economic grounds for reusing wastewater on this scale.

6 Local legal framework

The construction and renovation of the wastewater system is subject to a permit. The permit for the wastewater system of the new building is decided in the building permit process. Renovation of the old system usually requires a permit. Municipalities can also prescribe certain measures within the scope of the notification procedure in their building regulations. A wastewater plan drawn up by a professional must be submitted as an attachment to the application for a construction and operational permit.

The property owner is responsible for ensuring that the property has a functioning wastewater system that meets the basic cleaning requirement. In normal operation, the system must be able to remove 80% of the organic matter, 70% of the phosphorus and 30% of the nitrogen in untreated wastewater. In their environmental protection regulations, municipalities can tighten cleaning requirements and set restrictions on systems in sensitive areas. The environmental protection regulations also have protective distances that must be considered when placing the wastewater system. The wastewater system, which is insufficient in its cleaning power, must be renewed.

The responsibility for organizing water supply on the property in a way that meets the requirements of the law always rests with the property owner. Renovating an old wastewater system or building a new one always requires competent planning. The wastewater system plan must be submitted to the municipality's licensing authority as an attachment to the building permit application (new property or building) or to the operation permit application (renewal of the old system). A professional wastewater plan is also valuable regarding the contracting, use and maintenance of the system, possible changes, and resale of the property.

In Finland, the use and construction of areas is governed by the Land Use and Construction Act (132/1999) and the Decree (895/1999). The Land Use and Construction Act provides for the construction of wastewater systems in real estate and the quality of construction, as well as the qualifications of designers. New construction is subject to a permit, which means that a building permit is required and the property's wastewater treatment is decided in connection with the permit consideration. The condition of the building permit is that the organization of water supply and drainage must not cause special costs to the municipality and that wastewater must be able to be treated without causing harm to the environment.

Changing the wastewater system (renovation or major repair) is also subject to a permit. However, instead of a building permit, an operational permit is usually applied for from the municipality (Section 126 and Section 126a). In some municipalities, the construction of a wastewater system falls within the scope of a lighter notification procedure. If the settlement's wastewater is treated in a treatment plant larger than the population equivalent of 100, an environmental permit in accordance with the Environmental Protection Act (527/2014) is required for wastewater treatment and management.

Public procurement is regulated by the Procurement Act. Tendering for public procurement must be done in an open, equitable and non-discriminatory manner. Now and in practice the most economical option of the offers is to be chosen. This can mean the lowest price, the cheapest offer or the best value for money offer.

7 Activity

The design capacity of the current treatment plant is 4.5 m^3/d, in principle sufficient for processing water in the winter (about 2 m^3/d), a new treatment plant is needed for the summer. During the summer months, up to 12 times more wastewater is generated in the area than in the winter. The number of tourists is assumed to remain the same or even increase in the future.

As a result of the market dialogue, the municipality of Ingå received three offers as alternatives for a new wastewater treatment plant. The first was the same equipment as the one in use today, only sized for a larger number of users (Uponor, Wehoputs 120). Second offer was Vestelli Biocube Mars 120, which is a continuous wastewater bioreactor. According to the device's representative, its suitability for seasonal changes is good because it balances the load by recycling the sludge. The third option was the NT Waters (Busse GmbH) bioreactor with membrane technology. It's cleaning power is one of the best and no extra purification is needed to reuse of the water, but the purchase price is relatively higher.

Before receiving the environmental permit, the municipality of Ingå has not been able to make an official decision on the procurement. According to the Centre for Economic Development, Transport, and the Environment (ELY Centre), an environmental permit for the treatment plant is required if the estimated load coming to the treatment plant exceeds 100 PE. Based on the results of the July 2023 sampling, the Barösund treatment plant therefore needs an environmental permit.

8 Outlook

The outlined preparation work will lead to selection of the most suitable WWTS meeting the environmental, social, and economic criteria to overcome seasonality effect. The selected system will increase the degree of wastewater treatment while supporting local applicability and cost effectively guarantee effective nitrogen and phosphorus removal properties. However, the process will be delayed due to the environmental permit process. The permit process is well known by the municipality of Ingå thus safeguarding the smooth progress and enabling establishment of the new WWTS in summer 2024.

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Acknowledgement

The work has been carried out within the project NURSECOAST II, funded by the Interreg Baltic Sea Region Programme and co-funded by the European Union.

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K. Kuligowski & N. Effelsberg (eds.)
Technical preparation for wastewater treatment investments at BSR tourist destinations
Coastline Web 11 (2023), ISSN 2193-4177, ISBN 978-3-939206-31-6
S. 20 - 24

Pilot 3: Increasing capacity of already established plant for biological treatment of wastewater

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Abstract

The innovative use of nanobubbles is as a promising solution for municipal wastewater treatment. This comprehensive study focused on controlled generation and characterization of nanobubbles in an experimental setting located in Næstved, Denmark. This project lays the groundwork for optimizing wastewater treatment processes and holds global significance as a method to increase the capacity of existing small wastewater treatment plants and to avoid poor treatment of wastewater at peak periods e.g. in tourist areas. A pilot-scale plant featuring a Sequential Bio-Reactor (SBR) has been set up at Næstved Renseanlæg to assess the effectiveness of nanobubble technology. This ensures a highly flexible system for testing the solution and identifying optimal operational conditions. The nanobubble generator, being an external unit, can be easily installed at smaller wastewater plants. Vallensved, situated in Sealand, Denmark, is a compact plant designed for 700 PE, experiencing varying wastewater discharge rates between 55-162 m^3/day.

1 Pilot Site Description

The pilot plant is situated at Næstved Renseanlæg and comprises three IBC tanks. These tanks collect raw wastewater from the main plant, while the treated wastewater is recycled back into the system. The primary concept involves utilizing a nanobubble generator for aerating a wastewater treatment biological tank, aiming to enhance oxygen transfer and increase the tank's capacity.

If the results are positive, the plan is to establish nano bubble generator as an external unit at smaller plant e.g., Vallensved (700 PE).

2 Information on technology

Vallensved WWTP is a small biological wastewater treatment plant (mechanical treatment, biological treatment with nitrification). The biological tank is aerated using a surface aeration because of the low tank dept. It is an energy expensive method for aeration and not very effective. The idea is to improve the efficiency of the plant, so it can treat more wastewater especially in period with high wastewater load. Bottom aeration is not a possibility, so the idea is to test nanobubble addition as a method to improve the aeration.

A pilot plant has been established at Næstved Renseanlæg to evaluate the effectiveness of nano-bubble aeration in wastewater treatment. The pilot plant comprises three tanks, each with a maximum capacity of 1 m^3, configured as Sequential Bio-Reactors (SBR) as shown in figure 1.

The initial tank is equipped with a coarse-mesh filter to remove particles larger than 3 to 4 mm in diameter. Raw wastewater from the main treatment plant, after removal of large component (screening) and sand (sand trap), is introduced into this tank. Some of the heavier particles settle at the tank's bottom and are collected separately. The surface water is then pumped into the second tank, which incorporates a fine-mesh filter with a 1.5 mm diameter. In this tank, water is agitated using a turbine and oxygenated through a nanobubble generator. The nanobubble generator is connected to the SBR as an external unit, through which water from the SBR tank was pumped. The water flow rate ranged from 5 to 20 L/min, with an aeration rate of 60 mL/min (achieved by pressurizing air to 1.5 bar overpressure). Notably, in this configuration, over 90% of the energy consumption is attributed to water pumping. Before the test, the SBR was inoculated with activated sludge from the main plant.

The pumping sequence is outlined in table 1.

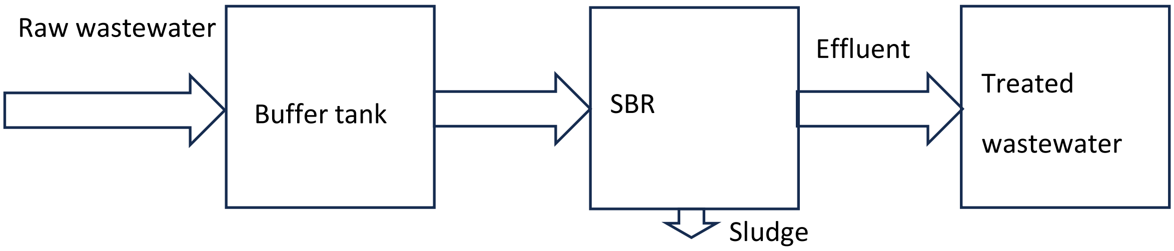

Figure 1: Sketch of the pilot plant with three tanks, each with a maximum capacity of 1 m^3. The initial IBC tank is a buffer tank for raw wastewater, followed by the Sequential Bio-Reactors (SBR). The treated wastewater is collected in IBC tank.

Figure 2: Pilot plant to test nano bubble technology (photo: Morten Lykkegaard Christensen).

After the biological treatment in tank 2, sludge is allowed to settle, and the resulting effluent is then pumped in to tank 3. The option to retrieve sludge from the bottom of tank 2 exists but has not been utilized so far as the sludge production was low. Various process durations have been tested and applied to fine-tune the wastewater treatment process. Oxygen, nitrate, and ammonium concentrations are monitored online, while suspended solids and COD are measured offline.

Table 1: Test protocol for the SBR as an example for one of the tests performed at the pilot-plant.

Process	Process time
Pumping from tank 1 to 2 (Aeration)	0 min
Pumping from tank 1 to 2 (Anoxic)	40 min
Aeration	60 min
Anoxic	40 min
Aeration	25 min
Settling	70 min
Pumping effluent from tank 2 – 3	15 min
Sludge removal	

For all experiments, we employed a nanobubble generator from Anzai (ANZAIKANTETSU CO LTD, Japan, AZ-UFB-Generator, AZ-015-0286). Nano bubbles are tiny air bubbles measuring 100-300 nm, remaining suspended within the water rather than rising to the surface. This property enhances aeration efficiency, with up to 90% of the added oxygen being transferred and dissolved in the water phase. Furthermore, nano bubbles remain within the water phase, preventing the formation of anoxic zones. Additionally, nano bubbles have the potential to generate free radicals in the water phase, which can enhance the degradation of organic materials, including micropollutants that may not undergo biological degradation.

The efficiency of the process, the purification efficiency, sludge formation, service lifetime and cost are not known yet and investigation of this will be a part of the study.

Our project centers on the use of nanobubbles, small and stable gas bubbles, to enhance the efficiency of treatment processes. Næstved, Denmark, serves as the backdrop for our experimentation, aiming to generate, characterize, and creatively utilize these nanobubbles. This unit is adaptable for integration into existing wastewater treatment plants with biological treatment in aerated tanks. It can serve as an external unit and in addition as a mobile option, providing additional aeration capacity during high-load periods. This study holds local and global importance, promising a more sustainable future for wastewater treatment.

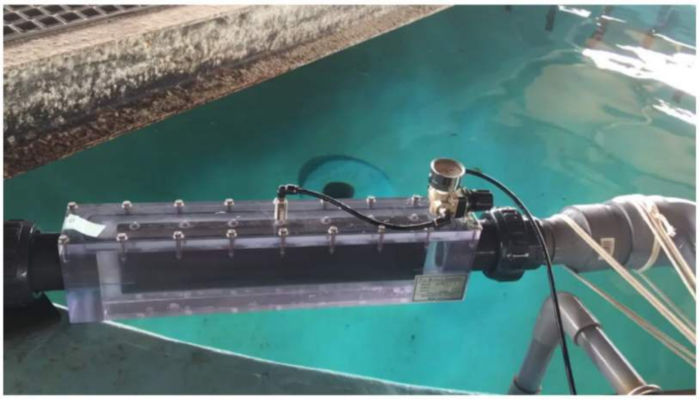

Figure 3: Anzii unit used for production of nano bubbles (photo: Morten Lykkegaard Christensen).

Figure 4: External nano bubble generator (Anzii unit) installed to produce nano bubbles, the unit have been connected to water pump and air supply (photo: Morten Lykkegaard Christensen).

3 Management

NK Forsyning has established the pilot-scale plant and oversees online monitoring of oxygen, ammonia, and nitrate levels. They are also responsible for operating and controlling the plant and for collecting samples for analysis, including COD, SS, pH, conductivity, and sludge floc size.

Aalborg University, in collaboration with NK Forsyning, will develop a testing program for the pilot plant to assess effluent quality, determine sludge production, aeration efficiency (specific aeration efficiency, SAE, and specific oxygen transfer rate SOTE) and calculate energy consumption. Testing costs will be shared between Aalborg University and NK Forsyning, with Aalborg University handling dissemination.

An external expert in biological SBR treatment will provide additional expertise.

4 Social impact

A pilot-scale system has been established to ensure that any potential failures or extended periods of absence do not impact the environment. Treated effluent and sludge are collected and pumped into the main wastewater treatment plant, so pure purification of the wastewater is not critical. Any issues encountered are documented, and proposed solutions are included in the final report. This system is designed as a simple external unit that can enhance the capacity of existing plants, offering ease of implementation. Additionally, it serves as an environmentally friendly alternative to constructing new plants, reducing construction-related carbon emissions. Moreover, it can effectively improve wastewater treatment during peak periods with high loads. The collected sludge can be transported to larger plants for potential reuse, particularly for phosphorus (P) and, to some extent, nitrogen (N), with a significant portion of the N being converted to atmospheric N.

5 Local legal framework

NK Forsyning are responsible of planning and launching the pilot project. One notable advantage of the nanobubble generator is its seamless implementation, free from regulatory hurdles.

6 Activity

Method is developed in the laboratory at Aalborg University for measuring concentration of nano bubbles in wastewater and distinguish it from dissolved oxygen. Procedure is developed to measure the concentration of free radicals formed when nano bubbles are burst. Technology that will be used at the pilot-plant to control the concentration and lifetime of nano bubbles. Test for measuring oxygen transfer rate, and nitrate removal rate will be established and used to test how fast oxygen is transferred to the liquid phase and whether it is possible to ensure anoxic condition which is critical to remove nitrate. Further settling rate will be measured, to see if pumping of sludge and adsorption of nano bubbles to sludge flocs will harm the settling rate.

7 Outlook

The project tests nanobubbles as a new solution for wastewater treatment, particularly in cases of high organic load or variable demand. The study at municipal treatment plants will address specific challenges, such as sludge degradation and nitrogen removal. Future work involves developing mathematical models to optimize nanobubble application, aiming to enhance wastewater treatment efficiency. This research has the potential to revolutionize wastewater treatment practices.

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Acknowledgement

The work has been carried out within the project NURSECOAST II, funded by the Interreg Baltic Sea Region Programme and co-funded by the European Union.

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K. Kuligowski & N. Effelsberg (eds.)
Technical preparation for wastewater treatment investments at BSR tourist destinations
***Coastline Web 11 (2023)**, ISSN 2193-4177, ISBN 978-3-939206-31-6*
S. 25 - 30

Pilot 4: Constructed wetland to treat wastewaster and produce water for irrigation

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Abstract

A constructed wetland is an appealing solution for wastewater treatment in areas with low wastewater production (below 500 units). Operating a constructed wetland is relatively straightforward, although the phosphorus concentration in the effluent may be higher when compared to conventional biological wastewater treatment methods. In tourist areas, especially those with fluctuating seasonal loads and high summer demand, using treated wastewater for irrigation can be an attractive option, utilizing phosphorus and nitrogen present in the treated wastewater as a valuable resource. In such cases, achieving high removal rates for phosphorus and nitrogen may not be critical. However, for plants where irrigation is not a possibility, alternative strategies for phosphorus removal are essential.

1 Pilot Site Description

A constructed wetland has been designed and installed at Skovgaard Gods, Denmark. It's designed to accommodate up to 60 population equivalents (PE) during the summer and 1-2 PE during the winter. This fit well with the constructed wetland where grow is most active during the summer period. Skovsgaard Gods is located in the countryside at Langeland in Denmark. The Gods is located with land surrounding it, providing the opportunity to place the wastewater treatment facility without causing disturbance to the surroundings. The distance to Rudkøbing (the largest town on the island) is 10 km, which has a wastewater treatment plant designed for 20,000 PE. An alternative solution to build a small wastewater treatment plant is to pump the waste water to the main wastewater treatment plant.

Figure 1: Location of constructed wetland at Skovgaard Gods (photo: Kilian Water).

It has been important to position the facility in a way that minimizes its visibility to visitors and mitigates potential odor issues. That is the reason for the placement behind the buildings (Fig. 1).

The basic principle is shown in figure 2.

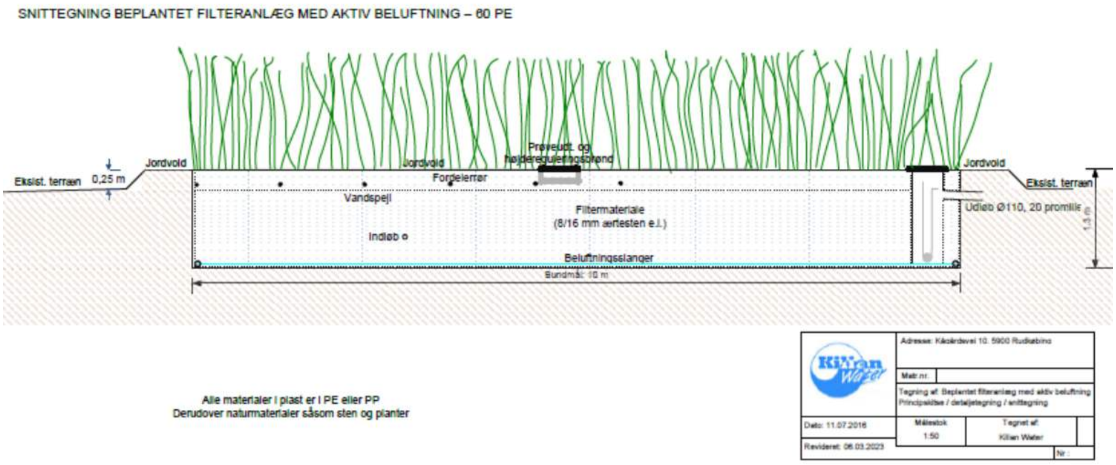

Figure 2: Principle of the constructed wetland (Kilian Water).

The design incorporates 1.0 m^2 of constructed wetland per PE, and the design has been based on the peak-period PE. The plant is situated above an infiltration unit. Aeration is employed in the constructed wetland to enhance mineralization processes, and thereby reducing the necessary wetland area per PE. A small blower is used to produce small air bobbles in the bottom of the constructed wetland with an even distribution-network for the whole area. Aeration time can be controlled and is max. 12 hours per day. The collected treated wastewater is utilized for irrigation purposes.

Figure 3: Pictures of the plant during construction (photos: Danmarks Naturfond).

2 Information on technology

Constructed Wetlands is a nature-based solution that can mimic natural processes to filter and treat water bodies using plants and microorganisms. This technology is then used to treat wastewater, reducing pollutant and improving water quality in a natural and sustainable way.

The operating mechanism of a Constructed Wetland involves wastewater flowing into a plant filter bed, inhabited by specific plant species such as *Phragmites australis* (Picture 1) or *Typha latifolia* (Picture 2). These plants promote a process called Phytoremediation (from Greek *Phyto*: plant and Latin *Remedium*: restoring; so, cleaning with plants), which removes pollutants and nutrients from water bodies, and it is aided by microorganisms that live on plant's roots and in the substrate. The output of this process is cleaner water, ready to be reused or safely discharged into the environment.

The main applications for Constructed Wetland technologies include different kind of wastewater such as Domestic, Industrial and Stormwater. Nevertheless, this technology can be used to create a sustainable habitat for the local fauna while treating the water bodies. More information can be found in David (2023)

Figure 4: *Phragmites australis*, also known as Common Reed (photo: Boroiu Cosmin, from Pixabay).

Figure 5: *Typha latifolia*, also known as Cattails (photo: Stefan Schweihofer, from Pixabay).

The technology is robust, capable of effectively managing varying loads. Its simplicity in construction, utilizing sustainable, locally-sourced materials, makes it a cost-effective investment (CAPEX) and economical in terms of operation and maintenance (OPEX). Additionally, it contributes to carbon dioxide absorption and offers ease of reusing treated water and valuable nutrients. The plant is manufactured by Kilian Water Ltd. The wanted purification efficiency is set to 10 mg BI5/l or 75 mg COD, and l - 5 mg NH_4 and l – 1.5 mg TP/l.

3 Planning the investment

Different partners are required for establishing the constructed wetland and several permissions (see chapter 6 Local legal framework). Danmarks Naturfond pays for the building activity besides the part financed by the project. Danmarks Naturfond is responsible for establishing the constructed wetland, Aalborg University is responsible for setting up protocols for testing the water quality after treatment, and test whether it can be used for irrigation. Danmarks Naturfond will find an area where irrigation can be done.

4 Management

Aalborg University will set up a test program. The test program will be presented and discussed with Danmarks Naturfond and the external project partner(s) involved in the design and establishment of the constructed wetland. A part of the study will involve monitoring the number of visitors at Skovgaards Gods for at least one season. comprehensive analyses on both the inlet and treated wastewater to determine the removal efficiency will be conducted, and data analysis will be done to see how plant load (PE), temperature, rain and season effect the removal efficiency. These analyses will encompass different parameters and will include COD (Chemical Oxygen Demand), suspended solids, pH, conductivity, total phosphorus, dissolved phosphorus, total nitrogen, and ammonia. Our primary focus will be on phosphorus removal, and we will explore strategies to further reduce its content in the treated wastewater. Additionally, we will investigate the impact of aeration on the treated wastewater and assess the extent to which we can control the removal of phosphorus and nitrogen. This includes the possibility of increasing the levels of these two nutrients during periods when the treated wastewater is employed for irrigation.

Aalborg University will be responsible for monitoring and control of the plant, eventually with help from Danmarks Naturfond for sampling. Most work will be done in the summer period, where the number of visitors is high. Aalborg University will be responsible for documentation of the plant.

5 Social impact

Danmarks Naturfond will be responsible for the arrangement, maintenance, and handling of the mineralized wastewater. The last point is not relevant within the project period. If problems arises and it is not possible to perform the study, it may be necessary to find another constructed wetland.

No restrictions on land usage are anticipated. Both nitrogen and phosphorus nutrients will be effectively recycled since the water will be used for irrigation. Additionally, a portion of the phosphorus and nitrogen will be naturally absorbed by the soil and plants within the constructed wetland. These nutrients can also be reused through plant harvesting and by spreading the collected material on agricultural fields.

6 Local legal framework

Several permissions are necessary for establishing the plant:

1) Infiltration or Waterbody Connection Permit: This involves obtaining permission to either infiltrate the treated water or connect to a waterbody, known as 'nedsivnings- or udledningstilladelse' in Danish.

2) Land Use Change Permit: This permission, known as 'landzonetilladelse' in Danish, is required when transitioning a specific area from one function (e.g., agriculture) to wastewater treatment.
3) Conservation Board Approval: This entails securing permission to construct facilities in a manner that does not visibly, audibly, or otherwise disrupt the existing surroundings.
4) Coastal Directorate Approval: If the construction is within 300 meters of the coast, permission from the Coastal Directorate is needed.

Danmarks Naturfond is responsible for securing all necessary permits, which have already been successfully obtained, and the construction phase of the plant is currently underway.

A research program will be established to explore the feasibility of utilizing treated wastewater for irrigation purposes. This study will involve gathering data to determine the necessary quality standards for irrigation water. Based on this, a program will be set up to conduct a thorough analysis of the treated wastewater quality, including critical measurements to assess its suitability for irrigation.

7 Activity

The constructed wetland has been completed, the plant has been established, and preparations are underway for its operation during the upcoming summer season. We are now entering the service and research phase of the project (Fig. 6), wherein the plant will be actively used for wastewater treatment, and research activities will commence.

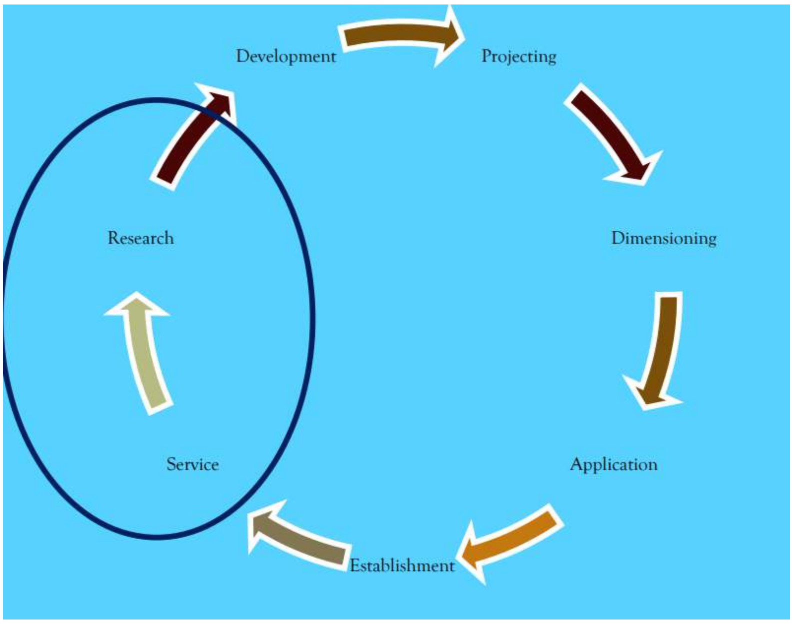

Figure 6: The project encompasses projecting, design, dimensioning, application, establishment, service, research, and development phases. The data gathered from this experiment will inform future iterations and designs of the project and beyond (Kilian Water).

During the winter period, test program will be set up, so we will be ready for testing the system during next summer.

During the next period, we will investigate various strategies for enhancing phosphorus removal when irrigation is not feasible. These strategies may encompass methods such as precipitation with iron salts or adsorption using materials like layered double hydroxide.

8 Outlook

As a result of this project, it is expected that it is possible to develop new and improved methods for reducing phosphorus concentration in effluent and enhancing the quality of treated wastewater for irrigation purposes. It is expected that the findings and techniques developed can be applied to numerous existing plants, especially in situations where water usage for irrigation is crucial during periods of high load, such as summer. Furthermore, it is expected that the outcomes will contribute to better wastewater quality if it needs to be discharged, potentially reducing phosphorus content.

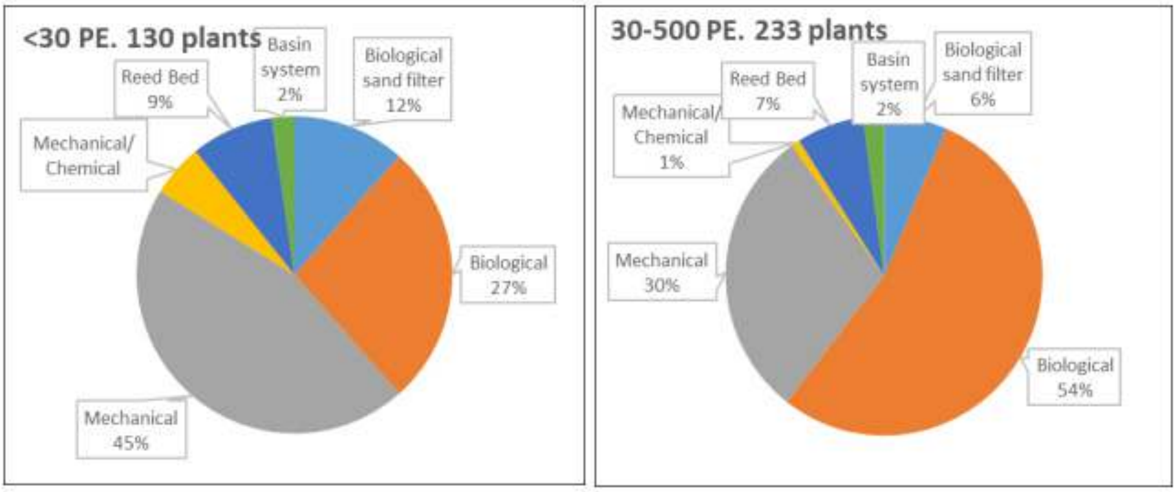

Figure 7: Type of treatment plant in Denmark. Plant designed for less than 500 PE (Morten Lykkegaard Christensen).

In Denmark, constructed wetlands make up 7-9% of wastewater treatment plants designed for less than 500 population equivalents (PE), indicating the potential for enhancing existing facilities.

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Acknowledgement

The work has been carried out within the project NURSECOAST II, funded by the Interreg Baltic Sea Region Programme and co-funded by the European Union.

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K. Kuligowski & N. Effelsberg (eds.)
Technical preparation for wastewater treatment investments at BSR tourist destinations
Coastline Web 11 (2023), ISSN 2193-4177, ISBN 978-3-939206-31-6
S. 31 - 40

Pilot 5: Expansion, filtration, disinfection, irrigation, monitoring for treated wastewater

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Abstract

The pilot facility is located in Poland, at the Bure Misie Settlement - an area with an average of 160 people during the summer and an average of 58 people during the rest of the year. As a result, the amount of wastewater produced at the Bure Misie Settlement is characterized by high seasonal variability. The biological wastewater treatment plant (75 PE) that has existed in the area since 2006 needs to be expanded and modernised to ensure a high level of wastewater treatment, taking into account the high variability of the volume of wastewater. A design for a new wastewater treatment plant, which will include a wetland, is currently under construction. After treatment, the wastewater is to be filtered and disinfected, and the resulting water can be used to irrigate green areas with ornamental plants. We expect that the treatment plant that will be built at Pilot 5 may help other small sewage treatment plants located in tourist areas to find the best solutions.

1 Pilot Site Description

The pilot facility is a wastewater treatment plant located in the Bure Misie Settlement, in Nowy Klincz, near Kościerzyna, in the Pomeranian Voivodship, Poland. The facility is located at a distance of ca. 50 km from the Baltic Sea, in the catchment area of the Wierzyca River, in the surface catchment area of the Vistula, which flows into the Baltic Sea. The area where the treatment plant is located is situated in the Lower Vistula water region.

According to data from 2017, Pomorskie Voivodeship is the second most attractive province in Poland in terms of tourism. In Kościerski poviat (administrative district), the dominant type of tourist value is that of nature (The Polish Central Statistical Office 2017).

The project site is located within the area of Surface Water Body (SWB, JCWP in Polish), the river SWB category, SWB code RW200010298173, named Wierzyca to Lake Zagnanie. The area in which the treatment plant is situated belongs to the direct catchment area of Lake Wierzysko.

In 2014-2019, the condition of the RW200010298173 catchment as ecological potential was assessed as bad. Indicators determining ecological status/potential: BOD5, ammoniacal nitrogen, total phosphorus, phosphate phosphorus (V); macrophytes, macroinvertebrates, ichthyofauna. The chemical status is below good and the indicator determining the chemical status is benzo(a)pyrene. The overall condition was classified as poor (State Water Holding - Polish Waters 2023).

In order to properly design and safely operate the facility, a ground investigation was commissioned in the area designated for the wastewater treatment plant. The ground investigation was carried out in two periods: September 2018, September 2023. A total of nine boreholes, each 5-6 m deep, were drilled in the area in question (Fig.1). Based on the geological investigations carried out, it was concluded that the area where the wastewater treatment plant will be built is characterised by a considerable spatial variation of ground conditions.

Figure 1: The ground investigation in Bure Misie Settlement (photo: Płuciennik M., BMCF).

In the subsurface ground the following was found:

- in the near-surface layer humus and embankments with a thickness of 0.3-1.1m,
- below alternately: sandy-clay silt (clsaSi) and sandy silt (saSi) and fine sand with silt (siFSa), medium sand (MSa), coarse sand (CSa), gravely sand (grSa) and gravel (Gr) (Bukowski J., 2023).

The terrain is slightly varied in elevation - it is elevated from 187 to 189m above sea level.

The frost depth is 1.0m (Bukowski J., 2023).

The Bure Misie Settlement (Fig. 2) is a seat of the Bure Misie Community Foundation. The Foundation has a servant role to the Bure Misie Community, established in 1983, which is a community of people with intellectual and/or physical disabilities and their friends. The mission of the Foundation is to provide shelter, care, rehabilitation and recreation for people with disabilities (The Bogdan Jański Bure Misie Community Foundation, 2023).

The Bure Misie Settlement includes six residential family houses (ultimately seven - the last to be built in 2024), a chapel, a farm, and a small cheese factory. The Settlement also includes an agritourism building, wooden camping cabins and a campsite - these facilities are used during the tourist season, which runs from the end of June to the end of August.

Sewage from the residential buildings and the cheese factory flows into the WWTP throughout the year, and during the holiday season also from the sewage system located in the camping area and the wooden camping cabins. A fat separator was installed in the cheese factory in 2023.

The collection of wastewater generated at the Bure Misie Settlement is carried out through a sewer network that delivers wastewater to the Bioekol-Mini 75 WWTP. Raw wastewater inflow to the treatment plant is mixed: gravity and pressure. The length of the gravity sanitary sewer network is 269 m, the length of the pressure sanitary sewer network is: 28 m and 110 m. In the course of the sewers there are two pumping stations.

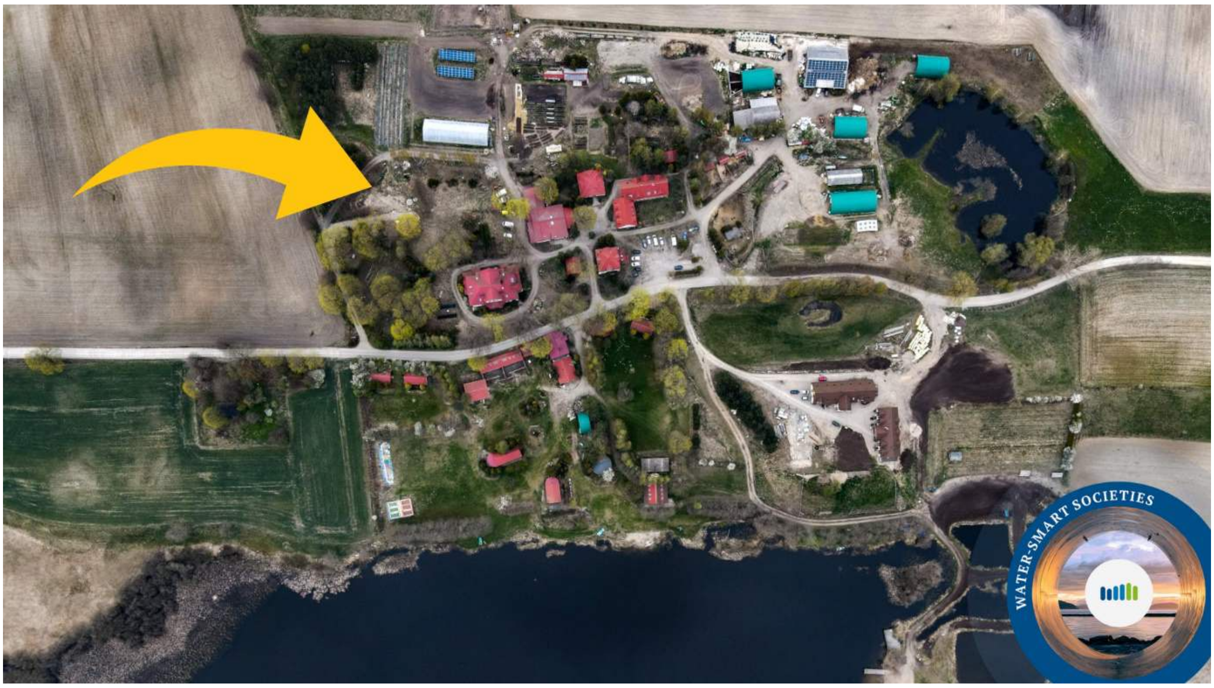

Figure 2: Location of the pilot facility. The Bure Misie Settlement. The location of WWTP is marked with an arrow (photo: Miliszewski T., BMCF).

2 Information on technology

Present state

The current wastewater treatment plant is a Bioekol Mini 75 model (Fig. 3), from Ecol-Unicon Sp. z o.o., based in Poland. It is a Mechanical-Biological WWTP. The treatment plant has a daily capacity of Q_d = 15 [m^3/d] and an hourly capacity of Q_{maxh} = 1,5 [m^3/h] (Malinowski A., 2005).

Figure 3: Mechanical-Biological WWTP: Bioekol Mini 75, in the Bure Misie Settlement (photo: Płuciennik M., BMCF)

The treatment plant consists of the following elements:

- mechanical treatment stage - primary settling tank, a two-chamber one with active capacity V=8.5 m^3 (PST1: φ =2000mm, PST2: φ = 1500mm).

- biological treatment stage - consists of a biological reactor, constituting a chamber of submerged biological deposits with an internal effluent filter,
- an installation well φ = 2000 mm
- a system of absorption wells, made of concrete circles φ= 1500 mm.

There are two blowers in the treatment plant: the power of the main blower equals 0.75 kW, the power of the auxiliary blower 160 W.

Table 1: Technological parameters of the current wastewater treatment plant (after: Malinowski A. 2005)

Bioekol Mini WWTP		PE	75
Capacity	daily Q_d	[m^3/d]	15
	hourly Q_{maxh}	[m^3/h]	1,5
Permissible pollutant load in raw sewage	TSS	[kg/d]	5,4
	BOD_5	[kg O_2/d]	4,5
	COD	[kg O_2/d]	9,0
	N	[kg N/d]	0,90
	P	[kg P/d]	0,112

A scheme of the wastewater treatment plant is shown in figure 4. A scheme of the bioreactor is shown in figure 5.

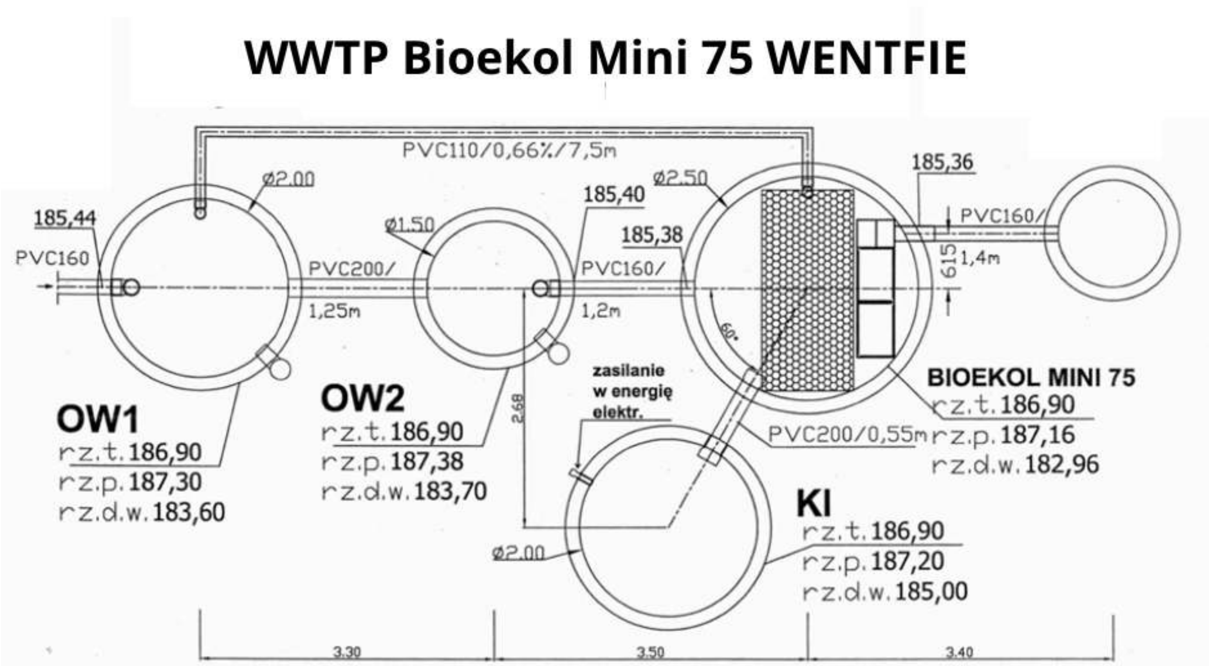

Figure 4: Scheme of the existing wastewater treatment plant. Key: rz.t. - ground elevation [m a.s.l.], rz.p. - cover elevation [m a.s.l.], rz.d.w. - internal bottom elevation [m a.s.l.], OW1, OW2 - preliminary settling tanks, KI - installation well, S3 - a well distributing treated sewage to absorption wells (Malinowski A. 2005, modified).

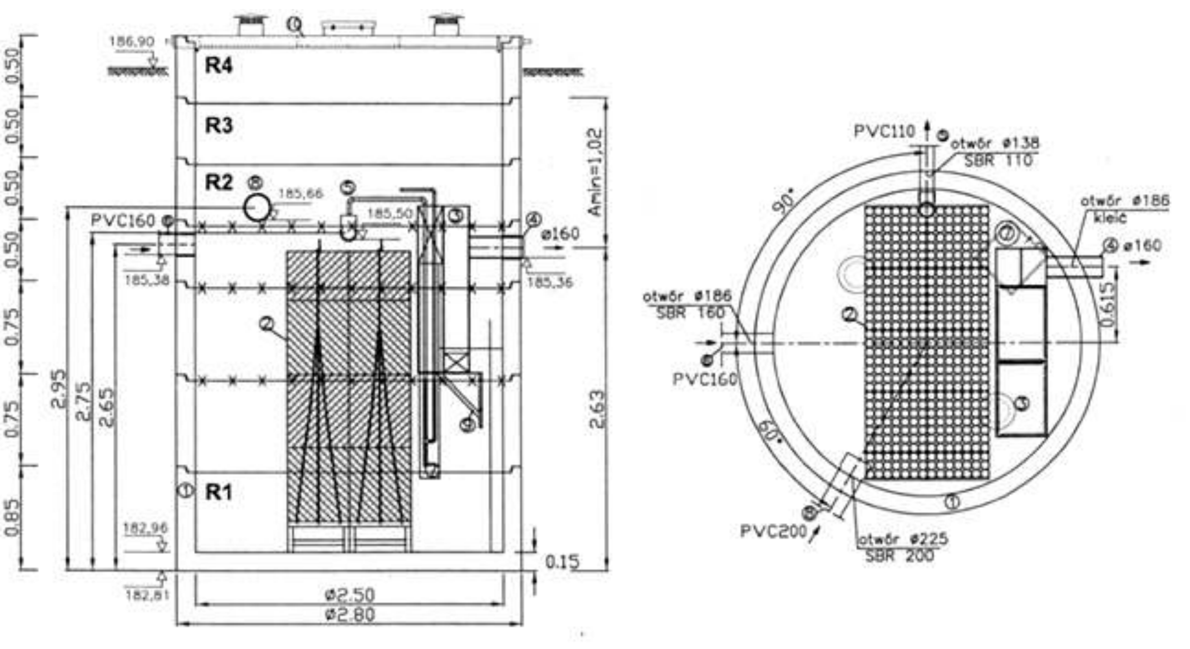

Figure 5: Scheme of the bioreactor at the current WWTP. 1- Concrete body, 2 - Biological bed, 3- Drainage filter, 4 - Waste water outlet, 5 - Secondary sludge discharge, 6 - Waste water inlet, 7 - Recirculation device, 8 - Air duct protection pipe, 9 - Support for left and right filters, 10 - Alumion cover (Malinowski A. 2005, modified).

The current treatment plant was put into operation in 2006.

In 2021, maintenance and modernisation works were carried out on the Bioekol Mini 75 treatment plant, in which the following activities were carried out: cleaning the wells, increasing the active surface area of the biological bed by adding new HDPE cubes of suitably shaped plastic with a specific surface area of no less than 200 m^2/m^3, replacing the aeration system in the biological reactor and adaptation of the treatment plant and connection to the Bumerang Smart monitoring system. The Bumerang Smart system allows a graphic view of the monitored facility in terms of the operation of a particular blower; the failure of a particular blower; and sending SMS alerts to designated mobile phone numbers.

In 2023, the treatment plant was equipped with a static energy consumption meter AC three-phase electricity consumption meter, LE-02d CT. The average daily electricity consumption is 13 kWh per day.

Also in 2023, a system was installed at the treatment plant to measure and record the amount of discharged wastewater. A Kama measuring choke and an ultrasonic level sensor were installed in the existing manhole separating the treated wastewater to the absorption wells. The signal from the sensor is transmitted via a cable route to a station recording hourly, daily, monthly and annual flows. (Kloska A., 2023). The volume of wastewater discharged for the non-tourist season is typically approx. 10 m^3/day, while during the tourist season approximately 20m^3/day. The maximum volume (peak) of wastewater for one day during the tourist season in 2023 was 26.5 m^3/day. Hourly values range from 0.1 m^3/h to 2m^3/h.

The catchment area in which the treatment plant is located is characterised by a high variability of wastewater volumes throughout the year.

Assumptions

The current treatment plant needs to be expanded and modernised, using technological solutions taking into account the high seasonal variability of wastewater volumes. It is important for the wastewater treatment plant to be effective both during the tourist season and the rest of the year. Expansion and modernisation of the current wastewater treatment plant must result in such degradation of the pollutants contained in the wastewater generated at the Bure Misie Settlement so that it consistently reaches values below those specified in the current water permit (2019):

- total suspended solids 35 [g/m^3],
- BOD_5 25 [g/m^3],
- COD 125 [g/m^3].

The maximum permissible levels for other parameters than those listed above are specified in the Regulation of the Minister of the Environment of 8 July 2004 on the conditions to be met when introducing sewage into waters and into the ground, and on substances particularly harmful to the aquatic environment (Journal of Laws No. 168 item 1763).

Wastewater treatment is to be carried out in two stages: First stage of wastewater treatment is by the biological WWTP, second stage of wastewater treatment is based on subsurface flow wetlands covered with common reed Phragmites australis or similar.

Constructed wetland is an example of the use of ecological engineering. Constructed wetlands may be applied to treat most pollutants that occur in wastewater (Fitch 2014). In systems enabling the development of hydrophytes, oxidation and reduction processes are intensified, which - supported by the processes of sorption, sedimentation and assimilation - enable the removal of a significant part of pollutants from sewage. Constructed wetland do not produce secondary sewage sludge and enable the removal of biogenic compounds: nitrogen and phosphorus, as well as specific pollutants, e.g. heavy metals (Gajewska et al. 2010).

Poland is a country with scarce freshwater resources. According to Eurostat, there is less than 1600 m^3 of water per inhabitant, which places Poland in the group of EU countries most exposed to water scarcity (Wyszkowska D. 2022). There is a need to carry out the modernisation not only of the WWTP, but also to find a solution for better water circulation in the area aiming at water reuse.

Once the WWTP has been expanded and modernised, it is to allow the use of treated wastewater for irrigation of green areas, what will be studied by a project scientific partner (Institute of Fluid-Flow Machinery Polish Academy of Sciences). A system for filtration and/or disinfection of the treated wastewater is to be used and the wastewater thus treated is to be collected for irrigation in a retention tank. It is also planned to test an IT system for remote management of the wastewater treatment plant.

In addition, nanobubbles technology will be tested on the biological section. Probes will be installed in this section to determine the pH level, redox potential, dissolved oxygen concentration and electrical conductivity. This will allow for the monitoring of changes resulting from the use of the nanobubbles generator in the bioreactor. The nanobubbles generator is shown in figure 6. This is the OZ-NM 2 device from AOZ Quingdao Aozengnier Purification Equipment Co, from China.

Figure 6: The device for generating nanobubbles (photo: Płuciennik M., BMCF).

3 Planning the investment

The Bure Misie Community Foundation has signed a contract for the creation of project documentation, together with obtaining the necessary permits, including: the preparation of a site development design, architectural and building design, technical design, complete bills of quantities of works, investor's cost estimate, decisions, arrangements, opinions necessary to complete the project and obtain a building permit, designers' statement on preparing the building project in accordance with the applicable technical and building regulations and the principles of technical knowledge.

Upon receiving the complete project documentation, the BMCF plans to carry out the selection of a Contractor to carry out the extension and modernisation of the wastewater treatment plant at the Bure Misie Settlement, within the framework of the project #C015 NurseCoast-II: Model Nutrients Reduction Solutions in Near-Coast Touristic Areas, Interreg Baltic Region 2021-2027 program, in accordance with the submitted documentation.

Construction work and launch of the treatment plant is planned for the first half of 2024.

BMCF's responsibilities to the Contractor include, among other things, providing the necessary projects, submission of permits and documentation needed to adequately perform the subject of the contract, introducing and handing over the construction site, providing investor supervision, timely acceptance of the subject of the agreement after checking its proper execution, and payment of the remuneration for completed and accepted works.

The obligations of the selected Contractor include, among others, execution of construction works based on the schedule approved by the Ordering Party, in accordance with the applicable legal regulations, design documentation, standards; securing the works area, training the user's personnel. The Contractor shall ensure that the works covered by the contract are performed and managed by persons with appropriate professional qualifications and construction qualifications, including the site manager.

The investment works will be paid for 80% from the project, 20% will be the costs incurred by the Ordering Party.

4 Management

With respect to the NurseCoast-II project, the Bure Misie Community Foundation has the following resources at its disposal:

- natural resources comprise a large area of land next to the existing wastewater treatment plant where a constructed wetland could be developed. Moreover, there is an access road leading to this area of land. There is an electricity supply, and it is possible to access running water near the treatment plant.
- physical resources comprise an existing wastewater treatment plant, a nano bubble generator, a building that could be used as accommodation for construction workers.
- human resources are three people employed on the project on a part-time basis for project management, administration, communication, promotion and finance, on-site control of the WWTP.

The design of the WWTP, construction of the treatment plant, installation of the equipment, wastewater surveys, land surveying and future supervision are all outsourced tasks.

Design documentation is prepared by an external company, by a person with unlimited design rights.

5 Social impact

The treatment plant is designed for automatic operation. The Bumerang Smart system informs about alarm situations regarding the operation of the blowers or failure or lack of power supply. Blower operation can be either automatic or manually controlled. The design of the treatment plant makes it possible to repair or replace components in the event of possible failure. Regular maintenance and regular sludge removal are necessary. At present, a specialised external company is responsible for sludge removal; sludge removal takes place every quarterly.

The investment is being carried out on land owned by the Bure Misie Community Foundation.

The treatment and management of the wastewater does not affect land belonging to third parties (Hej I. 2019).

The project area is located within the geodesic area of Nowy Klincz, Kościerzyna municipality. The area is entirely covered by the local spatial development plan. The wastewater treatment plant will be located in the area designated in the local plan as 79.UT - areas of tourist services development.

When carrying out the investment, it is necessary to apply technical and organisational solutions limiting the above-standard impact of the planned investments with respect to emission of air pollutants to the values specified in separate regulations.

There is an obligation to use earth masses, meeting soil or earth quality standards, obtained as a result of earthworks in the areas of their formation for land shaping, including for arranging greenery accompanying investments, with a permit to remove excess earth masses outside the areas of the plan in accordance with separate regulations. There is an obligation to preserve the existing tree planting and an obligation to secure rainwater in such a way as to protect the area against water erosion and the backing up of rainwater.

The access road to the wastewater treatment plant is a private road belonging to the BMCF, the construction works will not cause traffic obstruction on public roads.

6 Local legal framework

The BMCF is responsible for the entire implementation of the pilot investment.

In Poland, it is necessary to obtain a water permit, which is issued by State Water Holding – Polish Waters; a national water management authority. It is also necessary to obtain a building permit from the local authority. Once the permit is obtained, construction work can begin.

The Contractor for the construction works will be selected by means of an "Invitation to Tender", based on the criteria specified in this "Invitation...". It is advisable to receive three tenders and select the most advantageous one, according to the bid-at-three rule.

The contractor will be selected by a tender committee appointed by the BMCF Management Board.

7 Activity

At present, the average number of people staying at the Bure Misie Settlement is 58 (fluctuating between 45 and 70). During the holiday season (8 weeks), the number of people is around 160 (between 70 and 190). In the future, it is planned that there will be a slight increase in the number of people staying all year round at the Bure Misie Settlement to 65 people, and in the holiday season to 170 (peak-time maximum as 200).

As a result of the measurements so far, it can be assumed that the volume of wastewater during the tourist season is about 20 m^3/day and the volume of wastewater during the non-tourist season is about 10 m^3/day.

The current quality results of the raw wastewater tested are shown in table 2. Samples for testing were taken using autosamplers (12 samples taken per 24 hours), by a certified external company.

Table 2: Wastewater load – the raw wastewater.

Date	18.07.2023	01.08.2023	17.08.2023	18.09.2023
BOD_5 [mg/l O2]	300	990	1300	300
COD [mg/l O2]	588	1760	2390	629
TSS [mg/l]	120	950	370	160
N [mg/l]	101	157	133	47,2
P [mg/l]	8,2	36	18	6,8

8 Outlook

Once the current WWTP has been expanded and modernised, we expect to achieve the assumed ecological effect consisting of:

- increasing he degree of wastewater treatment, including the reduction of nutrients,
- introducing water reuse by using treated wastewater to irrigate areas with ornamental plants,
- increased knowledge on the impact of nanoaeration on wastewater parameters.

The establishment of the hydrophytic part of the WWTP at the Bure Misie Settlement, the reuse of treated wastewater and the testing of aeration technology using nanobubbles may help to find the best solutions for other small wastewater treatment plants facing high seasonal variability in wastewater inflow.

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Acknowledgement

The work has been carried out within the project NURSECOAST II, funded by the Interreg Baltic Sea Region Programme and co-funded by the European Union.

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