Lahden ammattikorkeakoulu
Lahti University of Applied Sciences

# Energy Audit

## Case: Zdroje WWTP and Kurenala WWTP


LAHTI UNIVERSITY OF APPLIED SCIENCES
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Työn tarkoituksena oli selvittää Puolassa sijaitsevan suuremman Zdroje jätevedenpuhdistamon (177 000 AVL) ja Suomessa sijaitsevan pienemmän Kurenalan jätevedenpuhdistamon (5700 AVL) sähköenergian käyttöä. Tavoitteena oli saada selville jätevedenpuhdistamoiden vuotuinen sähköenergian kulutus, sähköenergian kulutus osaprosesseittain, vertailla sähköenergian kulutusta puhdistamoiden ja kirjallisuuden välillä sekä tarkastella puhdistamoiden jätevesien keskeisten parametrien puhdistustuloksia.

Työ toteutettiin osana IWAMA- Interactive Water Management -projektia (Interreg Baltic Sea Region, 2014-2020). Työ on osa isompaa tavoitetta luoda jätevedenpuhdistamoiden käyttöön itseauditointikonsepti, jonka avulla energiatehokkuutta voidaan laitoksissa lisätä. Konseptin kehitys alkoi suorittamalla energia-auditoinnit jätevedenpuhdistamoihin. Auditointien tarkoituksena oli hankkia tietoa jäteveden puhdistamoiden tilanteesta sekä konseptiaihion toimivuudesta. Lisäksi työssä käytettiin apuna kirjallisuuskatsausta koskien jätevedenpuhdistusprosesseja, jätevedenpuhdistuksen lainsäädäntöä sekä jätevedenpuhdistuksen energian kulutusta.

Keskeisimpinä tuloksina todettiin tutkittujen jätevedenpuhdistamoiden biologisten prosessien kuluttavan eniten sähköenergiaa verrattuna muihin osaprosesseihin, jäteveden puhdistamisen vievän enemmän sähköenergiaa Kurenalan jätevedenpuhdistamolla kuutiometriä kohden sekä todettiin useimpien keskeisten jätevesien parametrien puhdistustuloksien olevan lainsäädännön ja suositusten mukaisia. Lisäksi jäteveden käsittelyn osaprosesseihin annettiin kirjallisuuden perusteella vaihtoehtoja energiatehokkuuden kasvattamiseksi. Saadut tulokset yhdessä käytännön tiedonkeräystyön kanssa ovat osa auditointikonseptin jatkokehitystä.

Asiasanat: jäteveden puhdistamo, jäteveden puhdistus, energia-auditointi, energiatehokkuus

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ABSTRACT

The purpose of the study was to examine the electricity consumption of a larger wastewater treatment plant Zdroje WWTP (177 000 PE) located in Poland, and a smaller wastewater treatment plant Kurenala WWTP (5700 PE), located in Finland. The objective was to examine the electricity consumption of the Zdroje and the Kurenala wastewater treatment plants, compare the electricity consumptions between the treatment plants and with the literature and as well as to examine the reduction results of the wastewater treatment parameters.

The commissioner of the study was IWAMA- Interactive Water Management -project (Interreg Baltic Sea Region, 2014-2020) which provided energy audits to the Zdroje WWTP and to the Kurenala WWTP. Also, literature review concerning wastewater treatment processes, legislation of wastewater treatment and use of energy in wastewater treatment was used. The study is part of a bigger objective to create the smart energy audit concept for WWTPs to increase their energy efficiency.

As a result of the study, it appeared that biological stage of the treatment process consumed most electricity compared to the other stages of the treatment process in both WWTPs, the electricity consumption per cubic meter for wastewater treated was higher in Kurenala WWTP and most of the reductions of wastewater treatment parameters did fulfil the requirements of legislation and recommendations. In addition, energy optimization recommendations for the most energy consuming treatment stages of the WWTPs was introduced based on the literature. The results obtained together with practical data gathering are part of the further development of the audit concept.

Key words: wastewater treatment plant, wastewater treatment, energy audit, energy efficiency

CONTENTS

## LIST OF ABBREVIATIONS

| | |
|---|---|
| **BOD** | **B**iochemical **O**xygen **D**emand |
| **CHP** | **C**ombined **H**eat and **P**ower |
| **COD** | **C**hemical **O**xygen **D**emand |
| **DO** | **D**issolved **O**xygen |
| **EER** | **E**nergy **E**fficient **R**atio |
| **HRT** | **H**ydraulic **R**etention **T**ime |
| **HELCOM** | Baltic Marine Environment Protection Commission - Helsinki Commission |
| **PE** | **P**opulation **E**quivalent |
| **RAS** | **R**eturn **A**ctivated **S**ludge |
| **RBC** | **R**otating **B**iological **C**ontactor |
| **WWTP** | **W**aste**w**ater **T**reatment **P**lant |

# 1 INTRODUCTION

This study concerns energy audits which were done to Zdroje WWTP, Poland, and to Kurenala WWTP, Finland, during 2017. The commissioner of the study is IWAMA- *Interactive Water Management*- project, to whom one of the main aims is to develop and test the smart energy and sludge audit concept.

Wastewater treatment is always important for people´s health and for the environment. History shows that wastewater disposed without treatment does not do anything but harm: public health concerns, outbreaks of odors and diseases, eutrophication of sea and lakes, among other things. (Riffat 2013,1-2). The importance of wastewater treatment plants is rising because of growing population and rapid urbanization (Au et al. 2013).

Wastewater treatment plants consume a lot of energy, it is estimated that in Germany and in Italy the electricity consumption for wastewater treatment is about 1 % of the total consumption of the country. For other European countries, this may be a good estimation of their wastewater treatment electricity consumption. (Antoni & Longo 2016.) Because wastewater treatment plants require much electricity, it is wise to look for opportunities for energy efficiency and energy savings in wastewater treatment.

In order to look for opportunities for energy efficiency and energy savings, wastewater treatment plants should first investigate their energy consumption. This may be done by energy audits where the energy consumption of wastewater treatment stages is examined. After an energy audit, it is possible to look for opportunities for energy savings. By decreasing the amount of used energy, the operational and energy costs of a treatment plant reduce, and the carbon footprint and thus greenhouse gas emissions lower. Also, the energy self-sufficiency of a wastewater treatment plant enhances by looking for opportunities to produce heat and power, for example, from biogas.

Usually in an energy audit, the heat and electricity consumption of a treatment plant is investigated but this study only concentrates on investigating the electricity consumption of the Zdroje and the Kurenala wastewater treatment plants. The study begins with a literature review of energy efficiency in general and in wastewater treatment plants, continuing to the history of wastewater treatment, the legislation and the recommendations concerning wastewater treatment and to the general information of typical wastewater and sludge treatment processes. About the energy audit concept and methods is told in Chapter 4, followed by detailed information of the Zdroje and the Kurenala WWTPs, including the loads and reductions of the WWTP´s wastewater treatment parameters and the results of the energy audits. Chapter 7 introduce possibilities to improve energy efficiency in general in wastewater treatment plants and in Chapter 8 results of the electricity consumption between the Zdroje and the Kurenala WWTP and literature is compared, also the reductions of the wastewater parameters between Zdroje WWTP and Kurenala WWTP are compared in Chapter 8.

# 2 ENERGY EFFICIENCY

## 2.1 Energy efficiency in general

To be able to provide the same services using less energy means to be energy efficient. For instance, it is energy efficient to use LED-lights instead of an incandescent bulb because LED-lights use less electrical energy to produce the same amount of light than incandescent bulbs. (Clark et al. 2012.)

There are many reasons why energy efficiency is important besides one of the most important fact that it reduces $CO^2$ emissions and by that, it reduces climate change. By using less energy, the lesser energy is needed to generate at power plants and that reduces greenhouse gas emissions and improves air quality (EPA 2016). Energy efficiency reduces energy costs, improves the economy by creating jobs and it also improves national security by reducing reliance on the import of gas and oil. Energy efficiency usually has positive effects on the quality of life, for instance, energy efficient buildings are supposed to be warm in winters and cool in summers and energy efficient LED-lights do not have to be changed so often compared to an incandescent bulb, which saves time and money. (Alliance to Save Energy 2012.)

The European Union has committed and is taking actions to reduce climate change and enhance energy efficiency. The EU has set climate and energy goals itself for 2020. By 2020, the EU should cut down 20 % greenhouse gas emissions from 1990 levels, do 20 % improvement in energy efficiency and rise 20 % the share of renewables in energy consumption. In addition, the EU members should have a 10% share of renewables in the transport sector by 2020. (European Commission 2017a.)

The Renewable Energy Directive sets national targets for EU members how much they should raise the share of renewables in their energy consumption. For Poland, this share is 15 % and for Finland, it is 38 % by 2020. (European Commission 2015.) In Energy Efficiency Directive, there are specific policies and measures in order to achieve the targets EU has set. For instance, retail energy sales companies and energy distributors must achieve a yearly 1.5 % saving of energy, energy audits are compulsory for large companies, for energy consumers, there should be free and easy access to their energy consumption data and for a variety of products there should be energy efficiency labelling and standards. (European Commission 2017b.)

## 2.2 Energy in a wastewater treatment plant

In municipalities, the largest energy consumers are usually water utilities. All sections in wastewater treatment plants consume a lot of energy, for instance, the aeration of biological treatment and the mixing and pumping of wastewater and sludge. (Iwama project 2017.)

The energy consumption in a wastewater treatment plant varies depending inter alia on the size of the plant, the type of the aeration system, the requirements of the effluent quality, the type of the processes and of the age of the plant and equipment. Energy consumption in wastewater treatment plants is estimated to increase because the characteristics and the amount of influent vary and especially because the requirements of discharged wastewater are increasing. (Bodík &I, Kubaská M 2013.)

Next, the energy consumption of different wastewater treatment process sections is described. However, a typical wastewater treatment process is described later in Chapter 3. The preliminary section of wastewater treatment process with screens and grit chambers usually consume relatively little energy. In the primary section with primary clarifiers, energy intensity varies widely. According to the study done by Bodík and Kubaská (2013), for example, in Canada energy intensity of raw wastewater collection and pumping ranges from 0.02 kWh/m$^3$ to 0.1 kWh/m$^3$, in

Hungary the range varies 0.0045 kWh/m$^3$ to 0.14 kWh/m$^3$ and in Australia, the range varies from 0.1 kWh/m$^3$ to 0.37 kWh/m$^3$. In the secondary section of a wastewater treatment process, the energy consumption is highest compared to the other wastewater treatment sections. The main electricity consumer in a WWTP is usually aeration (Figure 1) and in an activated sludge process where sludge is mixed and recirculated in nitrification and denitrification processes, energy demand is high. (Bodík & Kubaská 2013.)

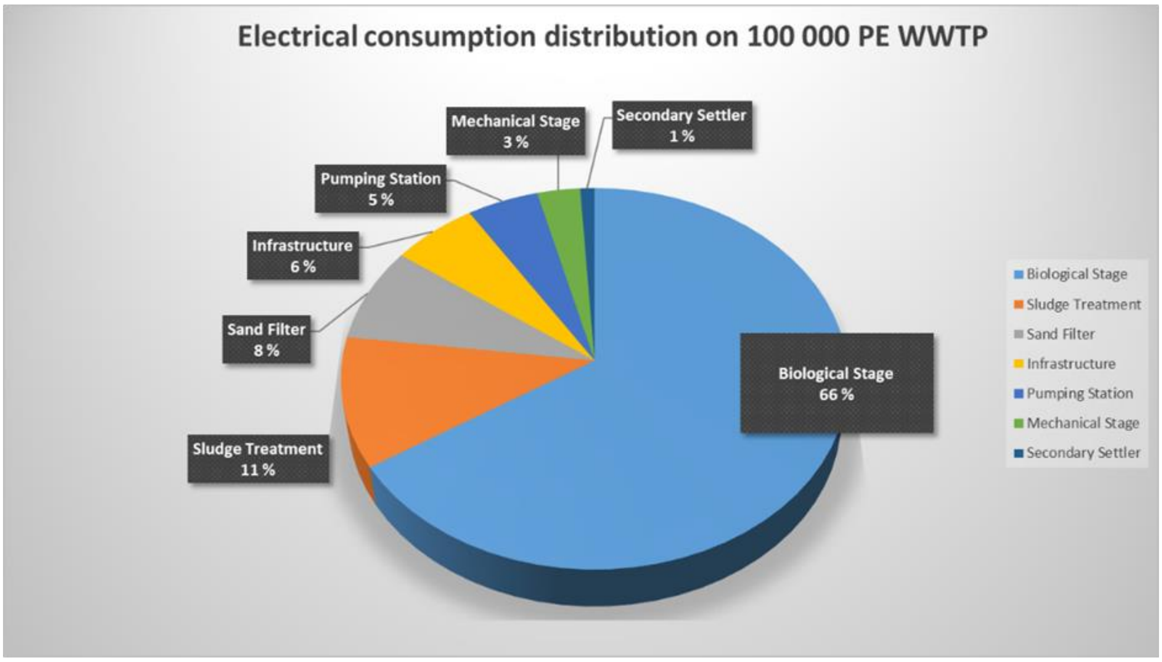


FIGURE 1. Distribution of electrical consumption on WWTP (Modified of the figure by Barjenbruch & Rettig 2017)

A conventional activated sludge treatment process with BOD removal in Australia consumes energy in average 0.46 kWh/m$^3$. In China the average energy consumption of conventional activated sludge process is 0.269 kWh/m$^3$. In USA, the average energy consumption is 0.33 - 0.60 kWh/m$^3$ and in Japan, it is 0.30 kWh/m$^3$ - 1.89 kWh/m$^3$. If there is an oxidation ditch in an activated sludge process, the energy demand is higher. In Australia, an activated sludge process with oxidation ditch consumes energy 0.5 kWh/m$^3$ - 1.0 kWh/m$^3$, in China 0.302 kWh/m$^3$ and in Japan 0.43 kWh/m$^3$ -

2.07 $kWh/m^3$. If the secondary treatment process is treatment with nutrient removal, for example, nitrification, denitrification or bio-P-removal, the energy consumption is relatively higher compared to a conventional activated sludge process, where only BOD removal is acquired. For example, in Japan, the energy demand of a treatment process with nutrient removal ranges from 0.39 to 3.74 $kWh/m^3$. (Bodík &I, Kubaská M 2013.)

According to Bodík & Kubaská (2013), the use of energy in wastewater treatment plants can be optimized and energy efficiency enhanced. Optimization can be done for instance, by replacing old devices inter alia pumps and mixers because old devices usually consume a lot of energy. In addition, newer equipment is usually equipped with frequency controllers, which save energy and optimize the operation of the process. (Bodík &I, Kubaská M 2013.)

There are different ways to optimize aeration system. It is important to maintain an appropriate amount of dissolved oxygen (DO) concentration in the aeration tank. If the dissolved oxygen concentration is too low, it can result in poor treatment results but if there is excess dissolved oxygen, it only wastes energy instead of improving treatment results. By Jenkins (2017) controlling DO concentration, energy consumption and treatment results can be optimized. For example, 25% to 40 % energy can be saved by operating DO and controlling the aeration system properly by manually controlled systems. (Jenkins 2017.)

Sludge thickening and heating can be optimized, and it is important to look for opportunities for electrical power production in a wastewater treatment plant (Bodík & Kubaská 2013). Looking for opportunities for heat recovery is recommended and by improving nutrient removal there is a chance to save 15% - 30% of energy (Iwama project 2017).

# 3 WASTEWATER TREATMENT

## 3.1 History of wastewater treatment

The wastewater management has developed from open dumping to collection and disposal without treatment to collection and disposal with treatment (Riffat 2013,1-2).

In the ancient Roman Empire, an evidence of open waste dumping to sewers and streets waste collection was found. In the seventeenth century, wastewater management consisted of latrines with an outlet constructed at a ground level that was discharged to a sewer or cesspools. This kind of wastewater management did not cause problems at the beginning, because the population density was low but when the population increased, the problems began. (Riffat 2013, 1-2.)

The problems were public health concerns, odors and outbreak of diseases. Public health care officials and scientists started to realize the relationship between contamination of drinking water and disease outbreaks from wastewater and the need for a sewer system not until mid the 1800s. The sewer system at that time was called water-carriage sewer system, which meant that the untreated wastewater was transported outside of the residential area to a river or a stream without any treatment. Cholera epidemics in London in 1848 and 1854 caused more than 25 000 deaths and Dr. John Snow first proved a connection between drinking water and wastewater. People who remained healthy were drinking water from the healthy part, upper stream of the river Thames and people who got sick of Cholera were drinking water from the sewage-contaminated part of the river. After that comprehensive water carriage-sewers was developed. (Riffat 2013,1-2.)

At the beginning of the twentieth century, primary treatment was used in wastewater treatment plants. Primary treatment included settling tanks, which removed suspended solids before the wastewater was discharged into rivers and streams. In 1976, the first activated sludge process was developed in Texas. Nowadays, the wastewater treatment process has developed and there are different types of biological and chemical processes to reduce pollutants in wastewater. (Riffat 2013,1-2.)

## 3.2 Recommendations and legislation

The main mission of a wastewater treatment plant is to treat sewage, even though energy efficiency is important. The most important legislation concerning wastewater treatment plants is the Water Law Act, Environment Protection Act and Directive 91/271/EEC – urban wastewater treatment (Falandysz & Sierota 2013).

Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. HELCOM has made recommendations for municipal wastewater treatment for the contracting parties which are Finland, Poland, Estonia, Denmark, Germany, Lithuania, Latvia, Sweden and the European Union. For wastewater treatment plants with a load more than 100 000-person equivalents, including the Zdroje WWTP with 170 000 PE, recommendations for treated wastewater discharges are shown in Table 1. (HELCOM 2017a.)

TABLE 1. HELCOM recommendations for treated wastewater 100 000 PE (HELCOM 2007)

| **Parameter** | **Maximum concentration** | **Minimum percentage of reduction** |
|---|---|---|
| | mg/l | % |
| $BOD_5$ | 15 | 80 |
| Total phosphorous | 0.5 | 90 |
| Total nitrogen | 10 * | 70-80 |

*"* Calculated as annual means. However, the requirements for nitrogen may be checked using daily averages when it is proved that the same level of protection is obtained. In this case, the daily average must not exceed 20 mg/l of total nitrogen for all the samples when the temperature from the effluent in the biological reactor is higher than or equal to 12 °C. The conditions concerning temperature could be replaced by a limitation on the time of operation to take account of regional climatic conditions" (Helcom 2007.)*

For wastewater treatment plants with a load 2000-10 000-person equivalents, including Kurenala WWTP with 5700 PE, recommendations for treated wastewater discharges are shown in Table 2.

TABLE 2. HELCOM recommendations for treated wastewater 2000-10 000 PE (HELCOM 2007)

| **Parameter** | **Maximum concentration** | **Minimum percentage of reduction** |
|---|---|---|
| | mg/l | % |
| $BOD_5$ | 15* | 80 |
| Total phoshorous | 1** | 80 |
| Total nitrogen*** | | 30 |

*"* Calculates as annual means with nitrification inhibitor*

*** Target value, calculated as annual means*

**** Total nitrogen means the sum of total Kjeldahl nitrogen (organic + NH4), nitrate (NO3)-nitrogen and nitrite (NO2) nitrogen." (HELCOM 2007.)*

The European Union´s Directive 91/271/EEC – concerning urban wastewater treatment, includes requirements for discharges from urban wastewater treatment plants. The aim of the Directive is to protect water environment from harmful effects of treated wastewater discharges and discharges from harmful effects. The requirements for treated wastewater discharges are shown in Table 3.

TABLE 3. Urban Wastewater Treatment Directive, requirements for treated wastewater (Urban Wastewater Treatment Directive 91/271/EEC)

| Parameter | Maximum concentration | Minimum percentage of reduction |
|---|---|---|
| | mg/l | % |
| $BOD_5$ | 25 | 70-90 |
| COD | 125 | 75 |
| Total suspended solids | 35 * (60 mg/l for 2000-10000 PE) | 90 * (70 % for 2000-10000 PE) |
| Total phoshorous | 1 | 80 |
| Total nitrogen | 10 ** | 70-80 ** |

*“* This requirement is optional*

***Alternatively, the daily average must not exceed 20mg/1 N. This requirement refers to a water temperature of 12°C or more during the operation of the biological reactor of the wastewater treatment plant. As a substitute for the condition concerning the temperature, it is possible to apply a limited time of operation, which takes into account the regional climatic conditions. This alternative applies if it can be shown that paragraph 1 of Annex I.D is fulfilled.” (Urban wastewater treatment directive 91/271/EEC.)*

## 3.3 Wastewater treatment process

Wastewater treatment process can be divided into sections. According to Riffat (2013, 3-4) the sections are primary treatment, which consists of a preliminary and primary treatment and a secondary treatment, which consists of biological treatment and secondary clarifiers. There are also advanced treatment processes, which can be included in the primary or secondary sections, such as phosphorous precipitation and nutrient removal.

In the preliminary treatment, larger substances and larger suspended solids are removed from wastewater. Usually, the preliminary treatment section includes screens and grit chambers. Screens are the first devices that wastewater encounters and they remove all the larger materials, which are flushed, such as toilet paper. Because raw wastewater can include anything, from toilet papers and rags to anything solid, screens prevent damages of pumps and other treatment process equipment. Grit chambers are sedimentation tanks, which are placed after screens and the purpose of grit chambers is to remove grit and other heavier solids from lighter biodegradable organic solids, like grease. Grit chambers prevent pumps and other mechanical equipment from abrasion and pipelines from blocks. (Riffat 2013, 93-94.)

After the preliminary treatment is primary treatment. The aim of this section is to remove rest of floating material, such as fats, and a large amount of suspended solids from wastewater by sedimentation or settling by gravitation. Suspended solids are heavier than water, therefore suspended solids settle to the bottom of the tank and are discharged for disposal or further treatment. By removing larger organic solids, it reduces the load of the secondary treatment. Primary clarifiers are rectangular or circular tanks, which are designed to achieve 25% - 40% BOD (biochemical oxygen demand) removal and 50 % - 70% removal of suspended solids (SS). (Riffat 2013, 99-109.)

The second section is secondary treatment. On the secondary treatment usually includes biological treatment and secondary clarifiers where sludge sedimentation or settling by gravitation occurs. For the biological treatment, the purpose is to remove the number of organic compounds, nutrients, such as phosphorous and nitrogen, and suspended solids in order to achieve acceptable levels. (Riffat 2013, 119.)

An activated sludge process is one of the most used processes in the biological treatment. A conventional activated sludge process consists usually of three sections. First is a section where microorganisms are kept in suspension and aerated in the tank called aeration tank, the second section is a secondary clarifier and the third section is a recycle system, which returns solids from the secondary clarifier to the biological process. First, wastewater flows in the aeration tank, where air is fed to keep the aerobic conditions in the tank and to mix the wastewater with the microorganisms. The microorganisms degrade organic matter in wastewater and convert organic matter to waste products and cell mass. The mixture goes to the secondary clarifier where the clarification occurs. In the secondary clarifier, part of the mixture operates as a return activated sludge (RAS), which is returned to the aeration tank in order to help to maintain an appropriate concentration of active biomass in the tank. The rest of the mixture is discharged for disposal or further treatment. (Riffat 2013, 126-127.)

### 3.3.1 Nitrification and denitrification

Activated sludge process with nutrient removal is commonly used. For nitrogen removal, the most used method is biological nitrification-denitrification process. In nitrification, ammonia is converted to nitrate which is shown in Equation 1 below. (Riffat 2013, 288.)

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O + energy \qquad [1]$$

Nitrification is a two-step process where two aerobic autotrophic bacteria genera called *Nitrosomonas* and *Nitrobacter* are in response for the treatment process. In the first step of nitrification *Nitrosomonas* oxidize ammonia to nitrite and in the second step, *Nitrobacters* oxidize nitrite to nitrate. (Riffat 2013, 288.)

In denitrification, nitrate is converted to nitrogen gas, which is released into the atmosphere. The process of denitrification is shown in Equation 2 below. (Riffat 2013, 291.)

$$NO_3^- \rightarrow NO_2^- \ NO \rightarrow N_2O \rightarrow N_2 \qquad [2]$$

Denitrification is also a two-step process. The first step is a reduction of nitrate to nitrite and in the second step, nitrite is reduced to a nitrogen gas. Denitrification requires anoxic conditions, which mean that there is no free oxygen. There are several genera of heterotrophic and autotrophic bacteria's, which can do denitrification, but the most common genera of bacteria are called *Pseudomonas*. (Riffat 2013, 291.)

### 3.3.2 Phosphorous removal

For a phosphorous removal, chemical precipitation is often used. Chemicals that are used to precipitation are metal salts and lime. The most often used metal salts are aluminum sulfate (alum) and ferric chloride. Also, by-products from steel making operations: ferrous chloride and ferrous sulfate are commonly used. With alum and iron salts, polymers are also effective to precipitate phosphorous. Lime is not used so often because it remarkably increases the mass of sludge compared to metal salts. Moreover, handling, feeding and storage lime are more difficult. Chemicals can be added in different locations of a wastewater treatment process. The first location where chemicals can be added is called pre-precipitation. In pre-precipitation chemicals are added to raw wastewater before primary clarifiers and the precipitated phosphorous is removed with the primary sludge. The second location is called co-precipitation where chemicals can be added either to the effluent from primary clarifiers, to the activated sludge process or before secondary clarifiers to the biological treatment process. The aim of the co-precipitation is that chemicals form precipitates that are removed with the excess sludge. The third location for adding chemicals is called post-precipitation where chemicals are added to the effluent from secondary clarifiers. In post-precipitation, chemical precipitates are removed in effluent filters or separate sedimentation facilities. (Metcalf & Eddy 1991, 306-307.)

After the biological treatment, the aim of the secondary clarifiers is to clarify the treated wastewater by settling the sludge to the bottom of the clarification tanks. Treated wastewater is discharged to environment, such as lakes or sea, but sometimes tertiary treatment is used, for example, an UV-disinfection, which neutralizes microorganisms (Trojan Technologies 2017).

## 3.4 Sludge treatment

In a conventional wastewater treatment process, sludge consists of a primary sludge from the primary clarification tanks and a secondary sludge, also called a waste-activated sludge or excess sludge, from the secondary clarification tanks. In the primary sludge, there are organic and inorganic particles from raw wastewater whereas in the secondary sludge, there are microorganism cells from the biological treatment process. Sludge is usually liquid or semisolid liquid, which contains 0.25 % to 12 % solids by weight. Sludge must be treated before disposal. There are regulations and quality standards for sludge before disposal because it may include, among others, pathogens, heavy metals and nutrients. (Riffat 2013, 239-240.)

Sludge can be treated in different ways. The first step of the sludge treatment is thickening. The aim of sludge thickening is to reduce the volume of the water content of sludge and, therefore, increase the solids content. When the sludge volume and the water content are reduced, it reduces WWTP`s pumping cost of sludge because the size of pipes and tanks for further treatment can be reduced. Some kind of a thickening method is in every wastewater treatment plant: in small WWTPs, the sludge thickening is achieved in the primary clarifiers and/or in the sludge digestion units, in bigger WWTPs, a separate thickening process is used. The main separate thickening processes are gravity thickening, flotation thickening, centrifugation, rotary drum thickening and gravity-belt thickening. (Riffat 2013, 246.)

The second step of a sludge treatment is usually sludge stabilization. The aim of sludge stabilization is to reduce pathogens, eliminate offensive odours and reduce the organic matter content of sludge. Not every wastewater treatment plants stabilize sludge after thickening. Some plants dewater thickened sludge and then after that stabilizes the sludge. The main sludge stabilization processes are alkaline stabilization (usually with lime), anaerobic digestion, aerobic digestion and composting. (Riffat 2013, 251.)

Anaerobic digestion is an energy efficient and traditional method to stabilize municipal sludge. In the absence of oxygen, concentrated organic and inorganic sludge matter is decomposed microbiologically and converted to methane, carbon dioxide and other end products. Anaerobic digestion stabilizes sludge, reduce the amount of it, and produces biogas. The process of anaerobic digestion is either a mesophilic process where temperature is around 35-40 °C or a thermophilic process where temperature is 53-57 °C. (PURE project 2014.) Produced gas from anaerobic digestion usually contains methane 65-70%, carbon dioxide 25-30% and small amounts of hydrogen, nitrogen, hydrogen sulfide, water vapour and other gases (Riffat 2013, 257). Produced biogas (mostly methane) is a source of renewable energy and can be used, for example, as a fuel for boilers or combined heat and power (CHP) plant units. Produced energy can be used, for example, to heat the operation building, to heat the sludge that is fed to digestion and/or to dry the sludge. (PURE project 2014.)

Usually, the third step of the sludge treatment is sludge dewatering to reduce the amount of water in the sludge. The aim of dewatering is to reduce more the volume of sludge because this way it is easier to handle and transport the sludge to the final disposal. Also, the reduced volume of sludge reduces the transportation costs. The solid content of dewatered sludge ranges from 20-30 %. Usually, dewatering is required before the treated sludge is suitable for composting, incineration or landfilling. The most used dewatering processes are centrifugation, belt-filter press and sludge drying beds. (Riffat 2013, 275.)

In large wastewater treatment plants, there might be a sludge thermal drying unit after dewatering. Sludge thermal drying reduce significantly the water content of sludge and increase the heat value of sludge for incineration. In addition, drying for agricultural disposal can be done but it is not so usual because of its high costs. The solid content of dried sludge ranges from 50 % to 90 %. The thermal drying process requires a thermal dryer unit, heat generation and distribution equipment, a biological filter for exhaust gases, a post-processing unit and a storage for the final product. (PURE project 2014.)

The last step for treated sludge is the final disposal. Methods for the final disposal are landfilling, land application with beneficial use and incineration. Advantages for land applications are, for example, the fact that treated sludge contains nutrients which are good for the plants and ground, therefore treated sludge with nutrients can replace chemical fertilizers and improve soil texture and water-holding capacity. Land application can be used on agricultural land, forestland, disturbed land and a dedicated land disposal site. Incineration is the complete combustion of organic matter in the sludge. The end-products of incineration are ash, carbon dioxide and water. Examples of combustion processes are multiple hearth incineration and fluidized bed incineration. By incineration, pathogens and toxic compounds are destroyed, there is a potential for energy recovery and maximum volume reduction is achieved. (Riffat 2013, 277-278.)

# 4 AUDITING CONCEPT AND METHODS USED IN THIS STUDY

One of the main goals of IWAMA- *Interactive Water Management* -project, the commissioner of this thesis, is to test and develop the smart energy audit concept for WWTPs. The first round of the energy audits was developing and testing step of the concept and was done in nine wastewater treatment plants across Europe from February to June 2017. The audits were done by an international group of students from Lahti University of Applied Sciences, Technical University of Berlin, University of Tartu and Linnaeus University with a help of supervisors from the universities. The writer of this thesis worked as a trainee in IWAMA project and was one of the auditing team members. Case Zdroje WWTP in Poland was audited in February 2017 with help of supervisors and students from the universities (including the writer of the thesis). Case Kurenala WWTP, in Finland, was audited in July 2017 by the thesis writer with the assistance of a student Joonas Kouvo from Lahti University of Applied Sciences.

The first step of an energy audit was to perform an energy review. In the energy review, the wastewater treatment process and sludge management were analyzed by every section of a particular WWTP. The energy review was done with a help of the Energy Analysis tool, made by Technical University of Berlin (TUB). The Energy Analysis tool is based on a German standard DWA-A 216. DWA is a German Association for Water, Wastewater and Waste and the DWA-A 216 standard includes instructions on energy check and energy analysis for wastewater treatment plants. In the energy review wastewater treatment sections are divided into stages which are:

- feed pump station

- mechanical cleaning stage

- biological cleaning stage

- secondary clarifier

- post-treatment

- sludge treatment

- sludge dewatering

- exhaust air cleaning

- other

- premises.

Because every wastewater treatment plant is different this division was adapted to different wastewater treatment plants.

In the energy review, a lot of information from a particular WWTP was collected and fed to the Energy Analysis tool. Among other information, collected data included general information of a WWTP, a biological and chemical oxygen demand, a concentration of nutrients (P, N), a number of aggregates, the operating hours of equipment and data about the treatment process.

In the energy review, it was important to collect information in written as well as to take pictures of the nameplates of motors, pumps and devices from each of the audited treatment plants. The nameplates (Image 1) usually include information of the magnitude of the nominal voltage (U), power factor (cos φ), installed power (P) and electricity actual stage (I), which is used when the yearly energy consumption of a treatment plant and different treatment stages are calculated. In addition, online energy meters were installed to some of the audited WWTPs to get information of the real-time energy consumption.


IMAGE 1. Nameplate of a primary clarification scraper in Kurenala WWTP (Kouvo 2017)

When all information was collected and fed to the Energy Analysis tool it was possible to calculate the yearly energy consumption of each treatment stage and review if there is any potential to reduce the energy consumption. The first round of the audits during 2017 was the development and testing step of the Energy Analysis tool and the concept. Developing of the concept continue during IWAMA project and the actual concept is aimed to be ready at the end of the IWAMA project, at the beginning of the year 2019.

# 5 ZDROJE WWTP

## 5.1 Wastewater and sludge treatment

Zdroje wastewater treatment plant (Image 2) (177 000 PE) is located in Szczecin, Poland. Szczecin is the capital of the West Pomeranian Voivodeship and the population is circa 420 000. It is located on the Oder River and circa 65 km from the Baltic Sea. (Kiiskinen & Sahlstedt 2010.)

IMAGE 2. Zdroje wastewater treatment plant (ZWIK 2016)

The wastewater treatment process of Zdroje WWTP consists of a primary and a secondary treatment (Figure 2). The primary treatment includes two coarse screens and three fine screens, aerated grit chambers and covered rectangular primary sedimentation basins. In the secondary treatment, there is a biological treatment with an activated sludge process and a bio-P process for a nitrogen and phosphorous removal. There are two aeration lines, which consist of a rectangular mixed anoxic zone, a mixed anaerobic zone and an oxidation ditch. In the oxidation ditch, there are aerated and non-aerated zones for nitrification, denitrification and BOD-removal. The biological treatment consists of two oxidation ditch units with anoxic and anaerobic reactors. The oxidation reaction is an oval-shaped channel with diffused aeration systems and mixing devices. This nutrient treatment process in the biological activated sludge process treatment, is called A$^2$O process. (Kiiskinen & Sahlstedt 2010.)

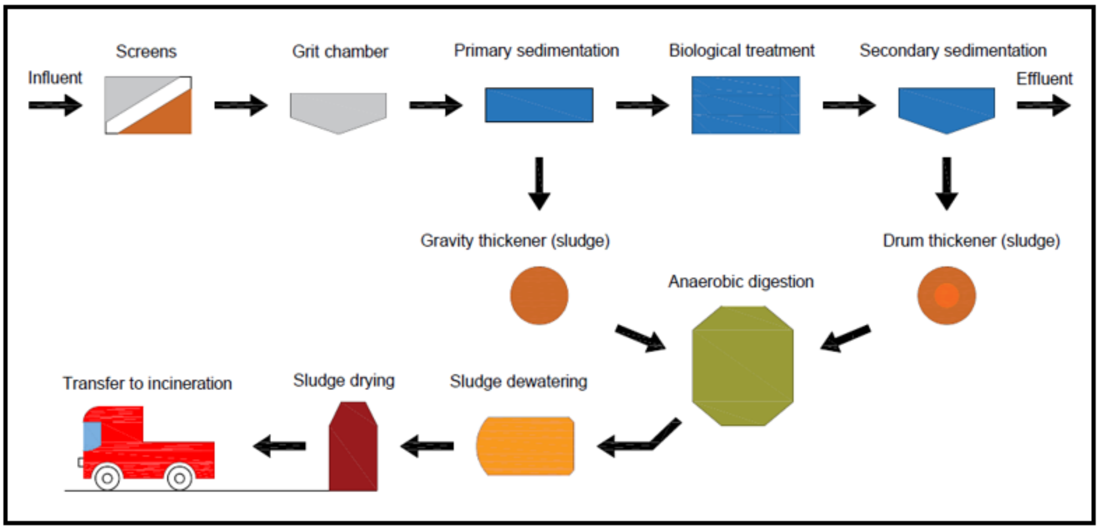


FIGURE 2. Wastewater and sludge treatment process of Zdroje WWTP

In the A$^2$O (Figure 3) treatment process, there are three phases. The first phase is an anaerobic phase where phosphorous is released. Polyphosphates, which are stored in bacterial cells, are converted to phosphates and released to wastewater. In the anaerobic stage, the hydraulic retention time (HRT) ranges from 0.5-1.5 hours. The second phase is an anoxic phase where denitrification occurs. For denitrifying bacteria, bound-oxygen in the form of nitrate is provided from the third section called an aerobic stage. Nitrogen is provided by recycling the wastewater from the end of the aerobic stage to the beginning of the anoxic stage. In the anoxic stage, the HRT is about 0.5 to 1.0 hours. The third phase is an aerobic stage where the formed nitrogen gas is released to the atmosphere, a carbonaceous material is oxidized, ammonia is oxidized to nitrate and the phosphorous is taken up. In the aerobic stage, the HRT is about 3.5-6.0 hours. (Pennsylvania Department of Environmental Protection 2014.)

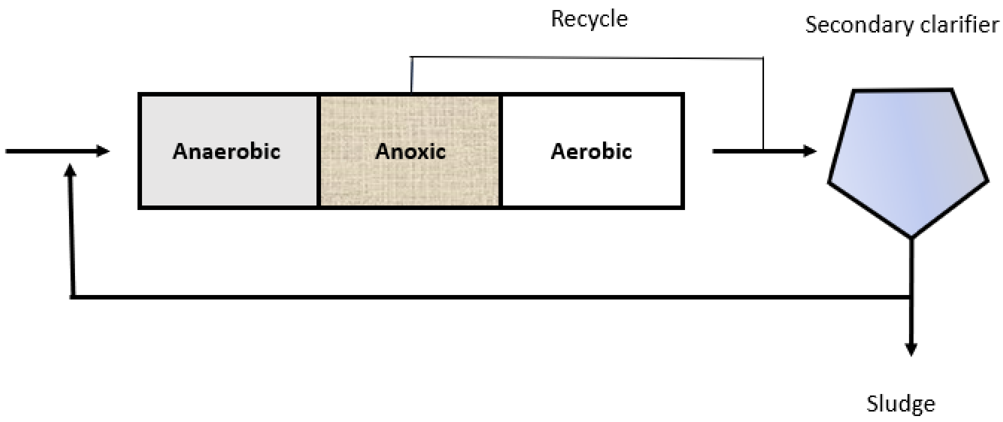


FIGURE 3. $A^2O$ process (Modified of the figure by Riffat 2013)

The last section of wastewater treatment process in Zdroje WWTP is a secondary treatment in two round basins. In these sedimentation basins, sludge settles to the bottom of the tank and treated wastewater is discharged into the Oder River. (Kiiskinen & Sahlstedt 2010.)

In the sludge treatment, the first stage is sludge thickening. Primary sludge is thickened in two round gravity thickeners and excess sludge is thickened in two rotary drum thickeners. Thickened primary sludge and excess sludge are mixed in an intermediate tank and from there, the sludge is pumped to anaerobic digestion. From digestion, the sludge goes to a storage tank and then it is dewatered with two centrifuges. After dewatering, the sludge is dried with thermal drying and finally transferred to Pomorzany WWTP, where incineration occurs. (Kiiskinen & Sahlstedt 2010.)

## 5.2 Wastewater flow

Zdroje WWTP´s daily inflow varied from 9392m$^3$/d to 30 006 m$^3$/day in 2016. The average flow was 14099 m$^3$/d. (Figure 4)

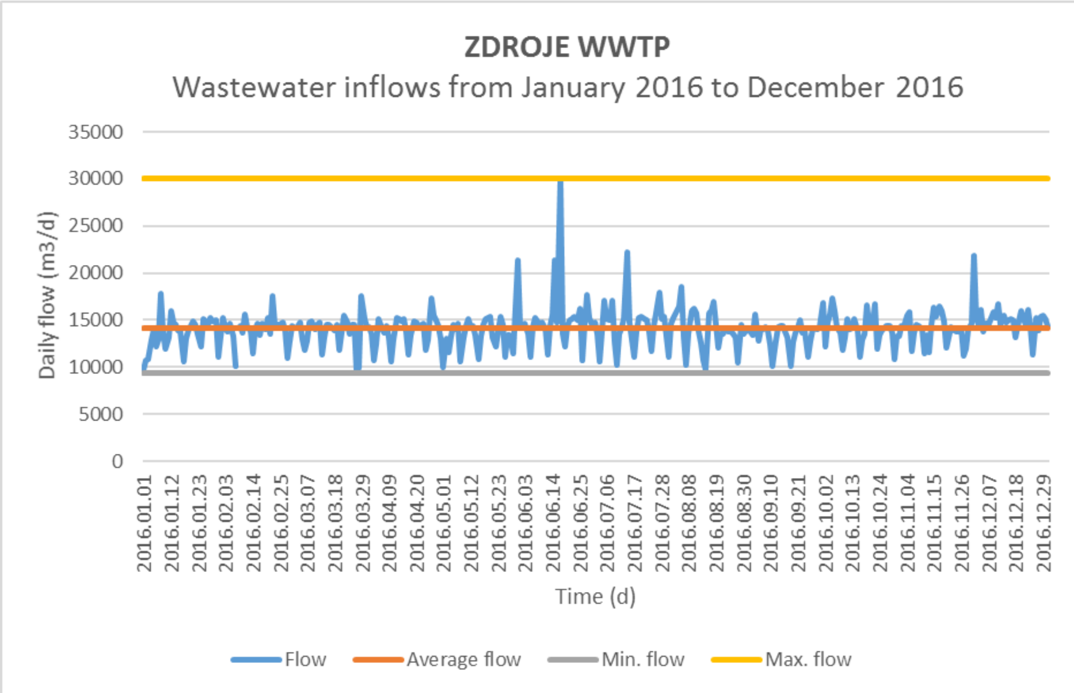


FIGURE 4. Zdroje WWTP inflow in 2016

## 5.3 Wastewater loads

Measurements of wastewater parameters ($BOD_5$, COD, suspended solids, total nitrogen, total phosphorous) was taken on average 10 times per month in Zdroje WWTP by WWTP staff in 2016. Data of parameters was given as concentrations (mg/l) and was converted as loads (kg/d) by the writer of this thesis.

### 5.3.1 $BOD_5$

The influent biological oxygen demand ($BOD_5$) load varied from 3477 kg/d to 18 599 kg/d in 2016. The average load was 9173 kg/d. (Figure 5)

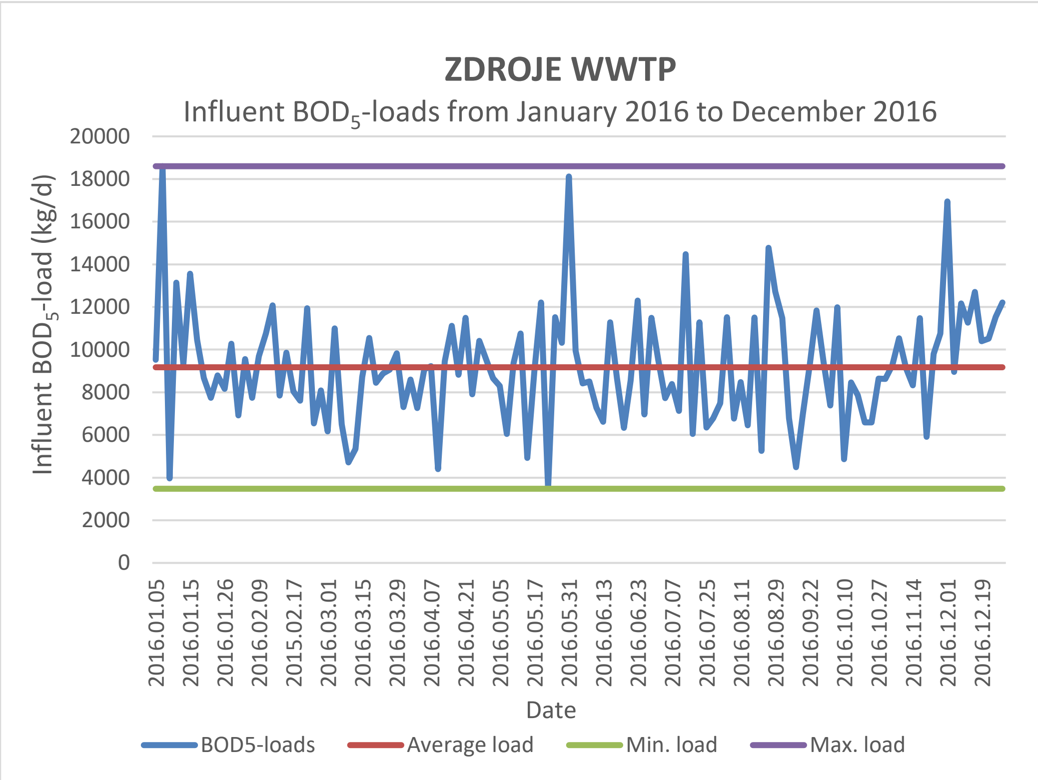


FIGURE 5. Influent $BOD_5$-loads in 2016

The effluent biological oxygen demand ($BOD_5$) load varied from 16 kg/d to 400 kg/d in 2016. The average load was 80 kg/d. (Figure 6)

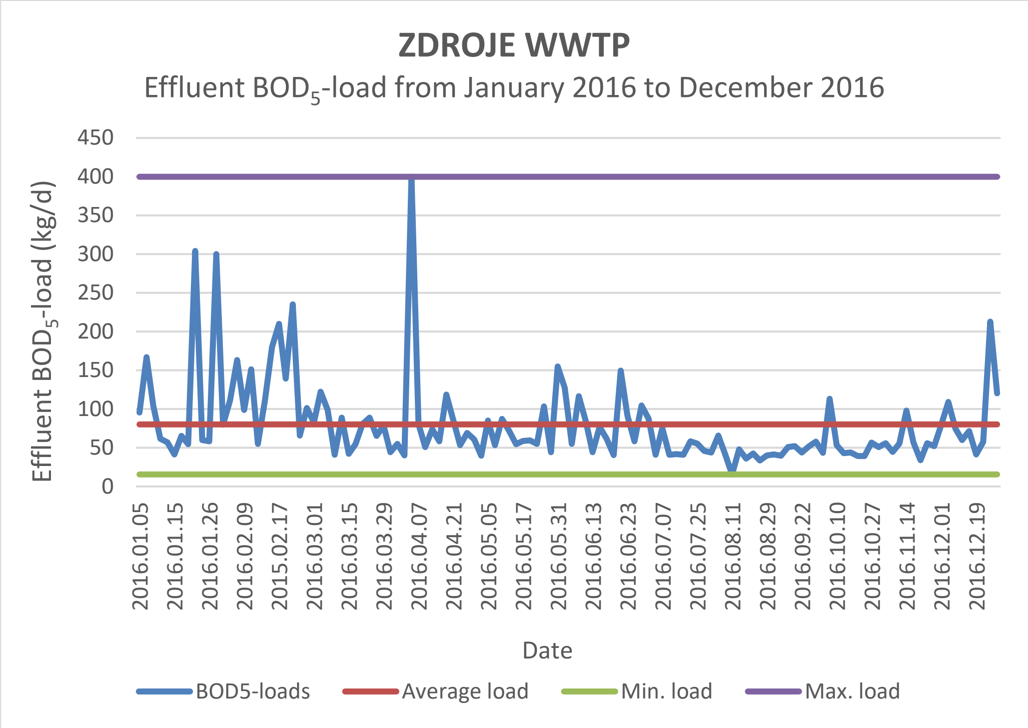


FIGURE 6. Effluent $BOD_5$-loads in 2016

The $BOD_5$ reductions in 2016 are shown in Figure 7. The minimum reduction is 95.3 %. The achieved treatment results fulfil the European Union´s Directive 91/271/EEC requirements ($BOD_5$ reduction 70 - 90%) and HELCOM recommendations where the minimum percentage of $BOD_5$ reduction is 80 %.

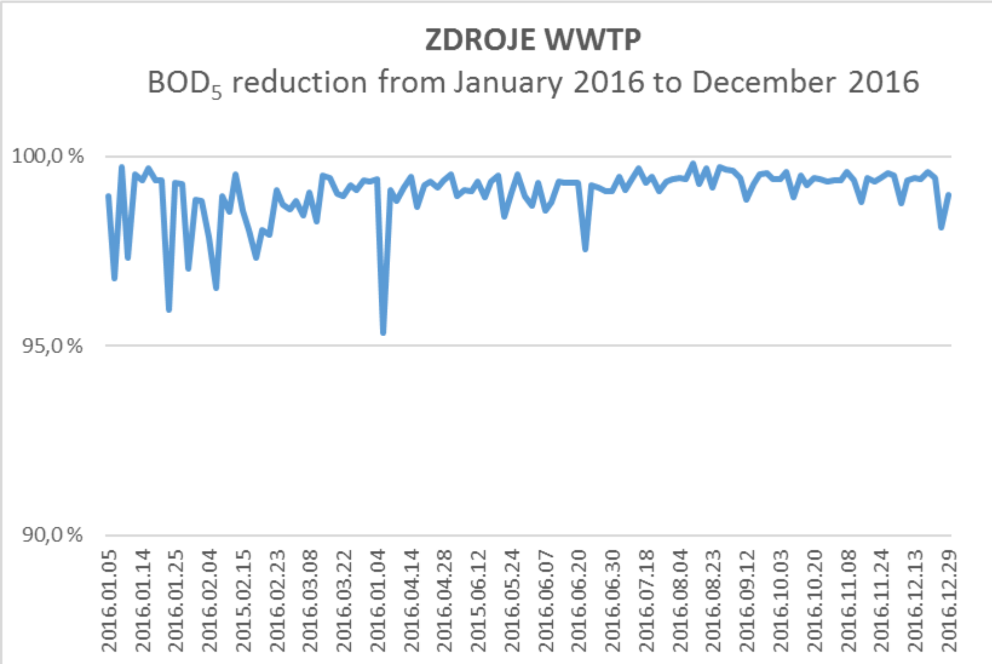


FIGURE 7. Reduction of BOD in 2016

### 5.3.2 COD

The influent chemical oxygen demand (COD) load varied from 7116 kg/d to 38 294 kg/d in 2016. The average load was 15 092 kg/d. (Figure 8)

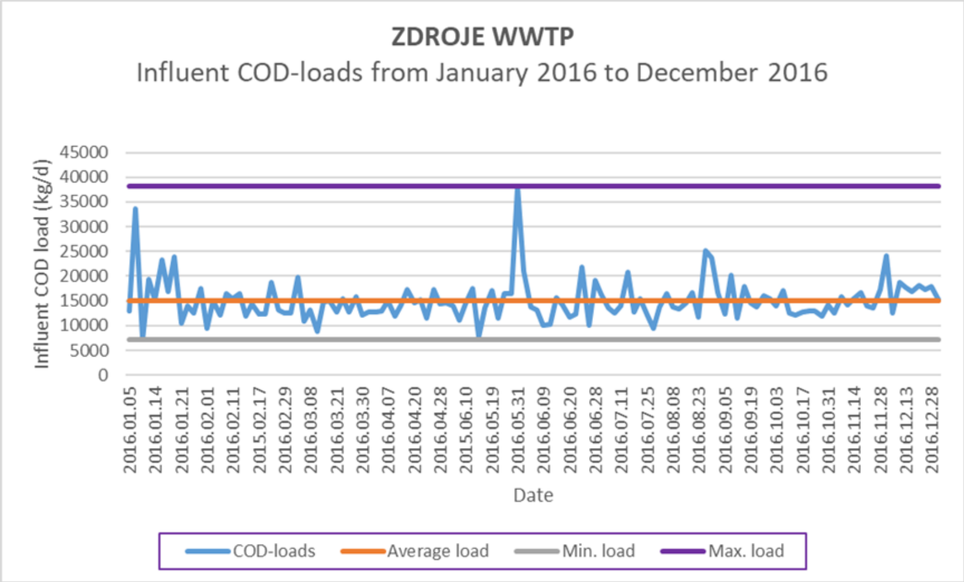


FIGURE 8. Influent COD-loads in 2016

The effluent chemical oxygen demand (COD) load varied from 315 kg/d to 2706 kg/d in 2016. The average load was 561 kg/d. (Figure 9)

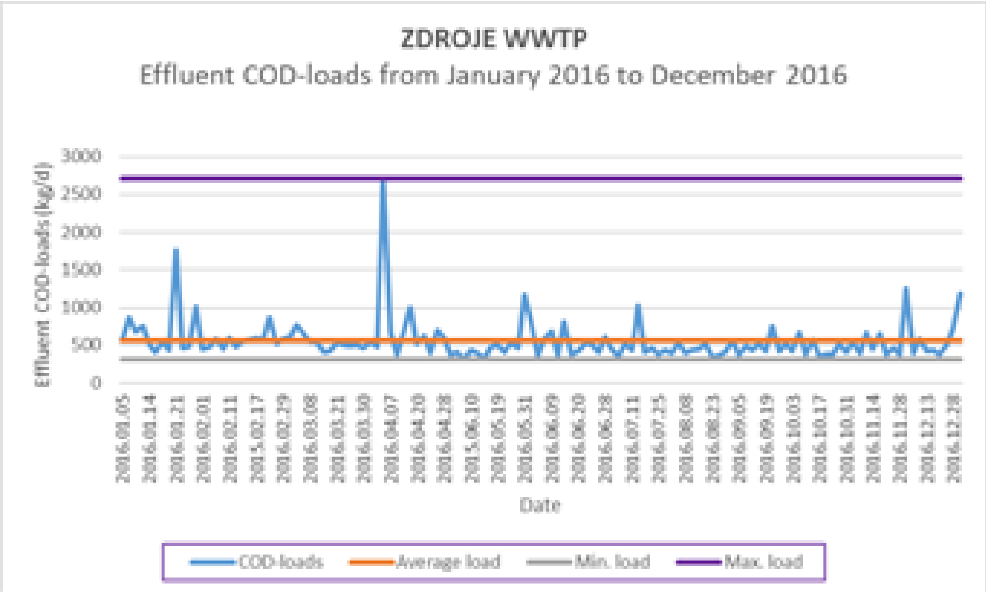


FIGURE 9. Effluent COD-loads in 2016

The COD reductions in 2016 are shown in Figure 10. The minimum reduction is 79.3 %. The achieved treatment results fulfil the European Union´s Directive 91/271/EEC requirements (COD reduction 75 %). HELCOM does not have recommendations for COD reductions.

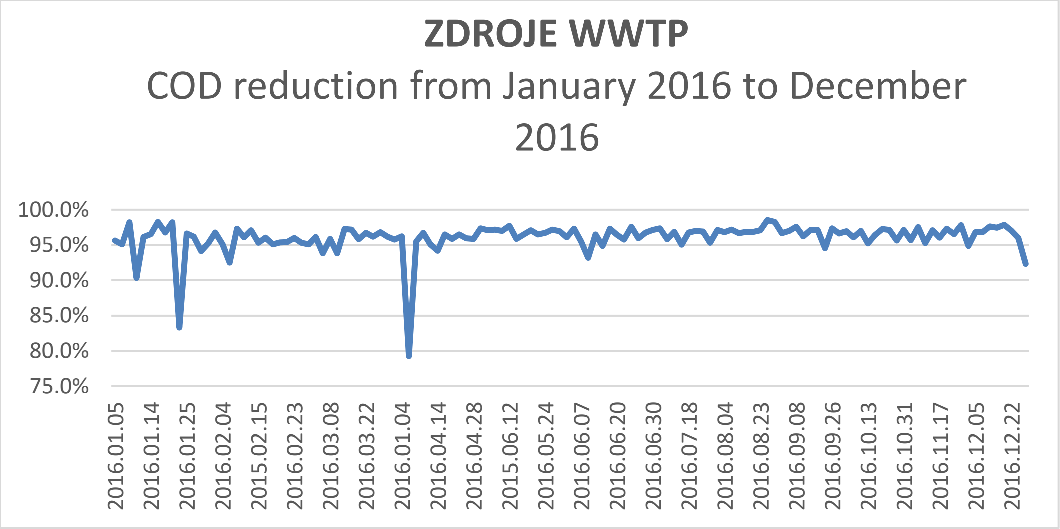


FIGURE 10. Reduction of COD in 2016

### 5.3.3 Suspended solids

The influent suspended solids (SS) loads varied from 1629 kg/d to 14 200 kg/d in 2016. The average load was 5593 kg/d. (Figure 11)

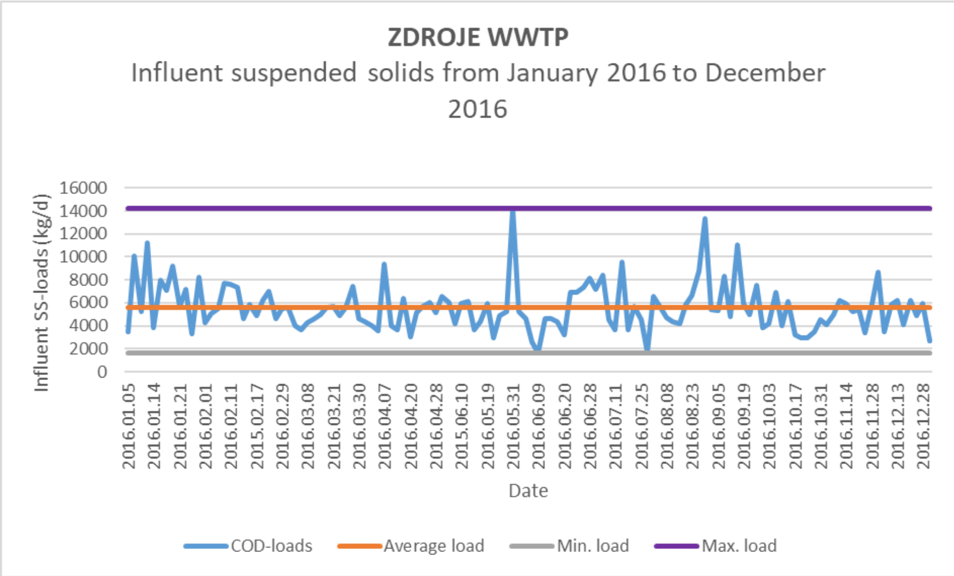


FIGURE 11. Influent suspended solids load in 2016

The effluent suspended solids (SS) loads varied from 31 kg/d to 983 kg/d in 2016. The average load was 132 kg/d. (Figure 12)

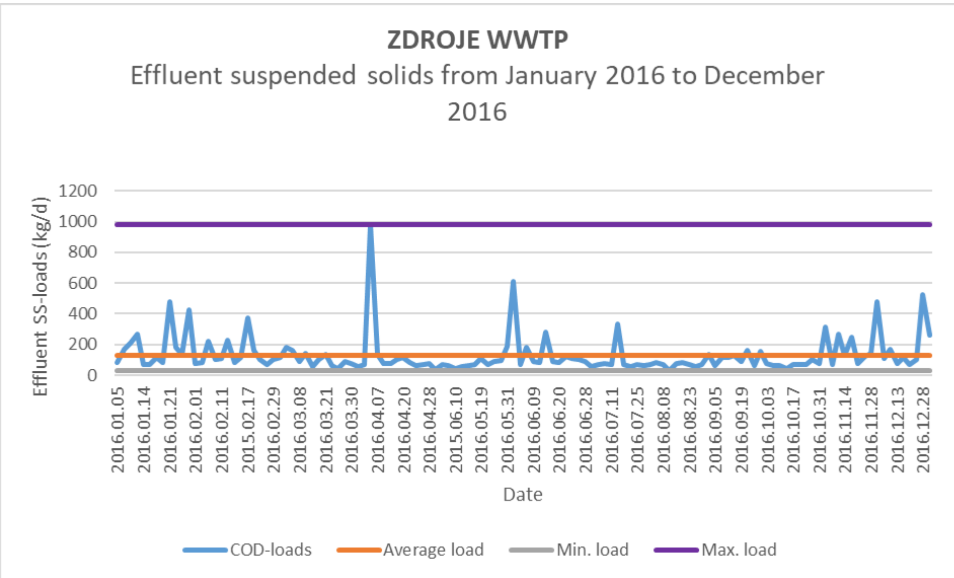


FIGURE 12. Effluent suspended solids load in 2016

The suspended solids reductions in 2016 are shown in Figure 13. The minimum reduction is 72.5 %. The achieved treatment results do not fulfil the European Union´s Directive 91/271/EEC requirements for suspended solids (reduction 90 %), but in the Directive, it is said that this requirement is optional. HELCOM does not have recommendations for suspended solids reduction.

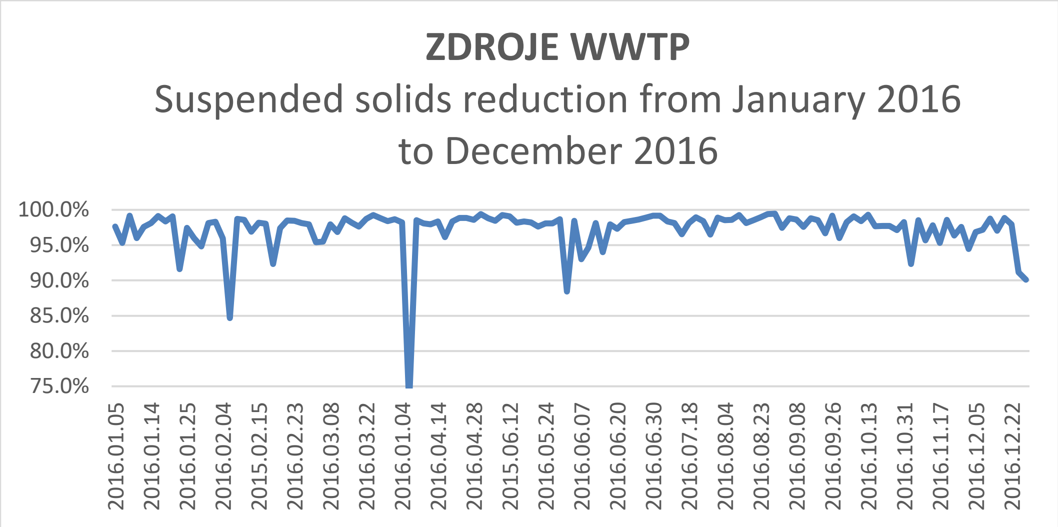


FIGURE 13. Suspended solids reductions in 2016

### 5.3.4 Total nitrogen

The influent total nitrogen loads varied from 973 kg/d to 3197 kg/d in 2016. The average load was 1574 kg/d. (Figure 14)

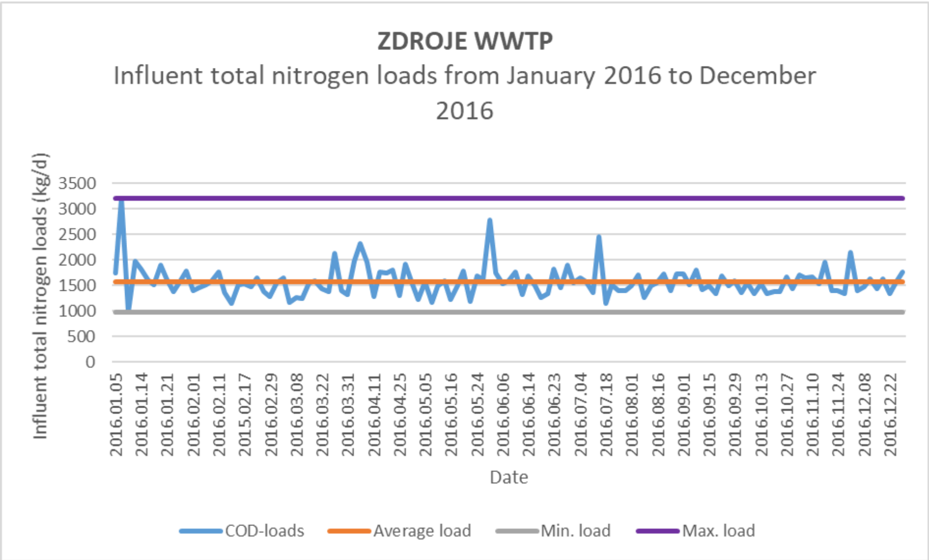


FIGURE 14. Influent total nitrogen loads in 2016

The effluent total nitrogen loads varied from 59 kg/d to 320 kg/d in 2016. The average load was 114 kg/d. (Figure 15)

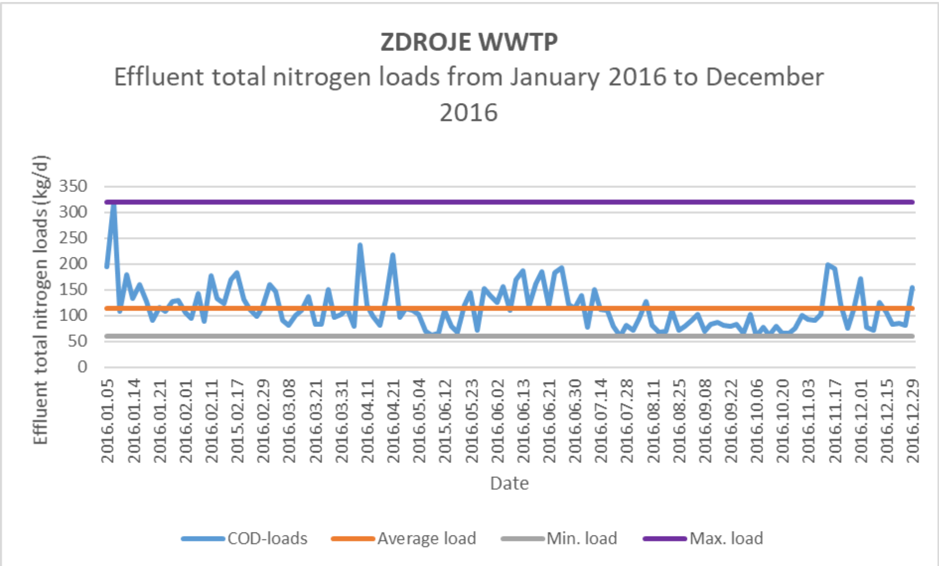


FIGURE 15. Effluent total nitrogen loads in 2016

The total nitrogen reductions in 2016 are shown in Figure 16. The minimum reduction is 86.7 %. The achieved treatment results fulfil the European Union´s Directive 91/271/EEC requirements for total nitrogen (reduction 70 – 80 %) and HELCOM recommendations where minimum percentage of total nitrogen reduction is also 70 – 80 %

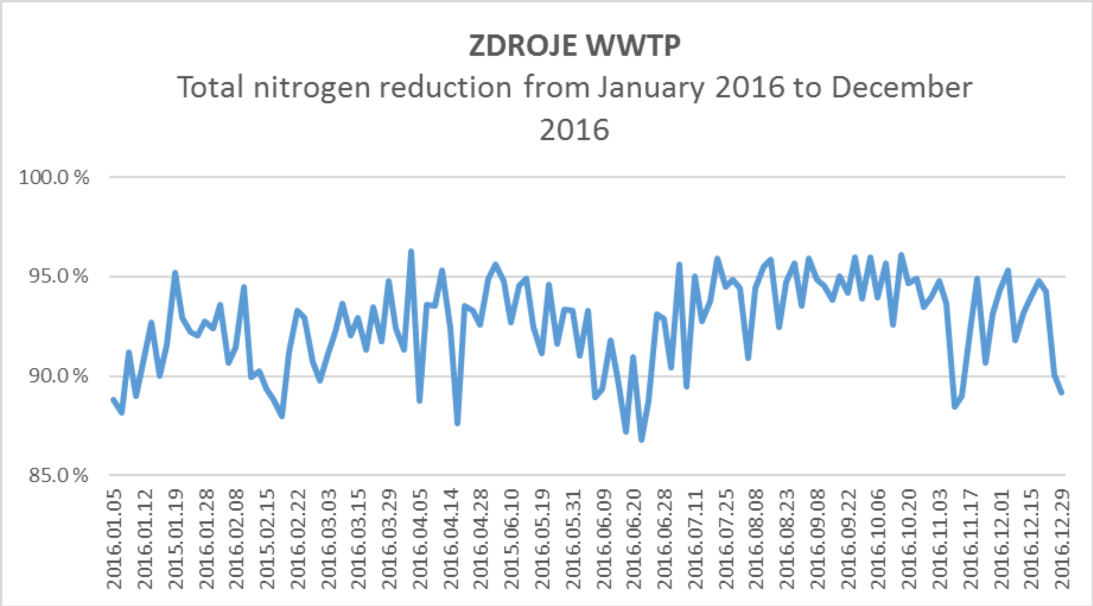


FIGURE 16. Total nitrogen reduction in 2016

### 5.3.5 Total phosphorous

The influent total phosphorous loads varied from 120 kg/d to 441 kg/d in 2016. The average load was 190 kg/d. (Figure 17)

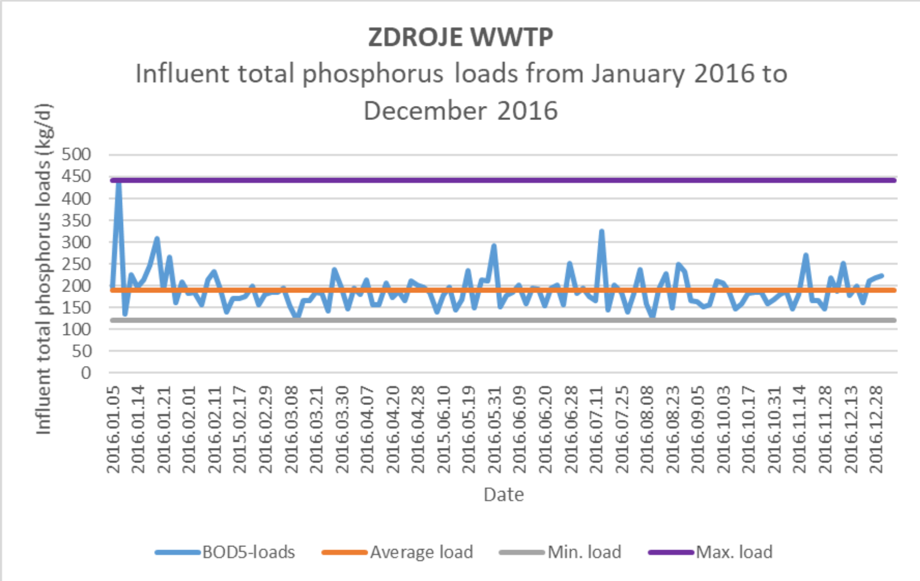


FIGURE 17. Influent total phosphorus loads in 2016

The effluent total phosphorous loads varied from 2 kg/d to 89 kg/d in 2016. The average load was 8 kg/d. (Figure 18)

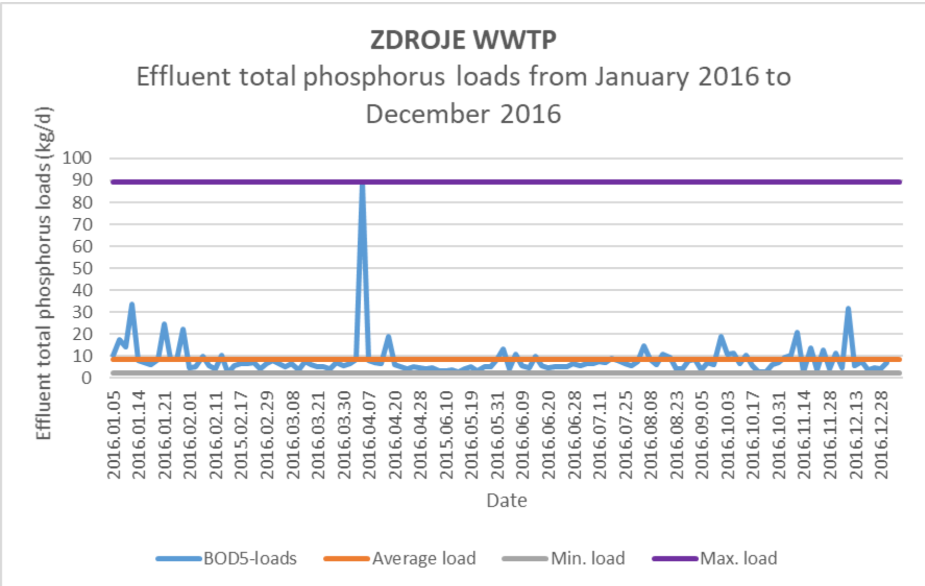


FIGURE 18. Effluent total phosphorus loads in 2016

The total phosphorous reductions in 2016 are shown in Figure 19. The minimum reduction is 50.8 % but only once in 2016. The achieved treatment results mostly fulfil the European Union´s Directive 91/271/EEC requirements for total phosphorous (reduction 80 %) and HELCOM recommendations where minimum percentage of total phosphorous reduction is 90 %.

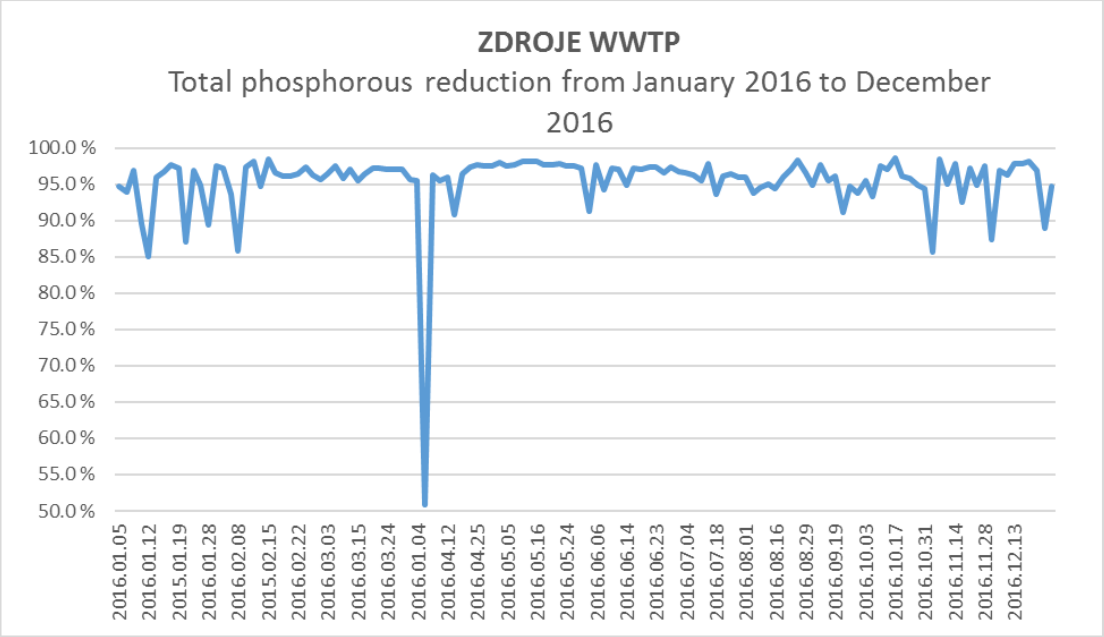


FIGURE 19. Total phosphorous reduction in 2016

## 5.4 Energy audit in Zdroje WWTP

The energy audit in Zdroje WWTP was executed in February 2017 with a help of the Energy Analysis tool (Appendix 1 & 2). Approximately 111 devices in Zdroje WWTP were considered during the first results of the energy audit. In Table 4, it can be seen a number of devices, which are divided by the different process stages. A more detailed energy consumption of devices is shown in Appendix 2.

TABLE 4. Number of devices in different stages of wastewater and sludge treatment processes in Zdroje WWTP

| Process Stage | Number of devices (pcs) |
|---|---|
| Feed pump station | 4 |
| Mechanical cleaning stage | 37 |
| Biological treatment stage | 19 |
| Secondary clarifier | 10 |
| Sludge treatment | 28 |
| Sludge dewatering | 12 |
| Other | 1 |
| **Total** | **111** |

The first process stage in the energy audit was the feed pump station, which collects and delivers wastewater to the next treatment. The second process stage was the mechanical stage which includes, for example, the motors of the screens and conveyors, grit and grease removal pumps, the movement motors of the grit chamber scrapers and the blower motor of the grit chamber. The third stage was the biological stage which includes pumps for return activated sludge, blowers for aeration and different kind of mixers and motors. The fourth stage was the secondary clarifier which includes the motor of the scrapers, pumps for excess sludge and other aggregates. The fifth stage was the sludge treatment which includes pumps and motors for sludge thickening and digestion and other aggregates. The sixth stage includes mixers, pumps and motors for polymer dosage station, such as sludge pumps among others for sludge dewatering.

According to the first results of the energy audit, the energy consumption in Zdroje WWTP was 2 815 465 kWh/a in 2016. Treating cubic wastewater in Zdroje WWTP consumed energy 0.55 kWh/m$^3$. The highest energy consumption stage in Zdroje WWTP is the biological stage, which consumes 64.6 % (~1 820 100 kWh/a) of the total energy consumption. The next highest energy consumers are the sludge dewatering stage 11.5 % (~323 200 kWh/a), the sludge treatment stage 10.1 % (~284 700 kWh/a) and the feed pump station stage 9.6 % (~269 600 kWh/a). The lowest energy consuming stages are the mechanical cleaning stage 3.8 % (~106 000 kWh/a), the secondary clarification stage 0.4 % (~10 500 kWh/a) and the “other” stage where the blower of the biogas consumed 0.1 % (~1 300 kWh/a) of the total energy consumption. (Figure 20)

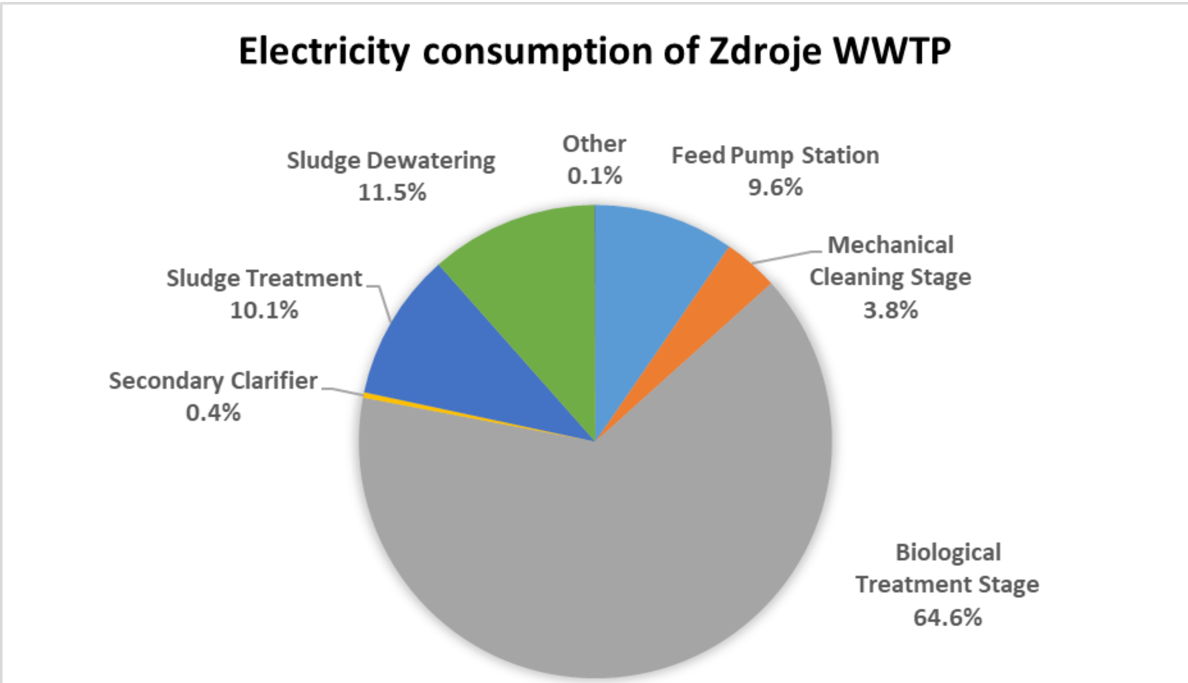


FIGURE 20. Electricity consumption distribution in Zdroje WWTP

# 6 KURENALA WWTP

## 6.1 Wastewater and sludge treatment

Kurenala WWTP (Image 3) (5700 PE) is located in Northern Ostrobothnia region in Finland, in the city called Pudasjärvi. The Pudasjärvi population is circa 8200 inhabitants. Treated wastewater is lead from WWTP to a pond called Siikalampi. (Salmela 2017.)

IMAGE 3. Kurenala WWTP (Salmela 2017)

The wastewater treatment process (Figure 21) of Kurenala WWTP consists of a primary treatment and a secondary treatment. The primary treatment consists of two screens, an aerated grit chamber and one rectangular primary sedimentation basin. In the secondary treatment there is a biological treatment with four rotating biological contactors (RBC). (Salmela 2017.)

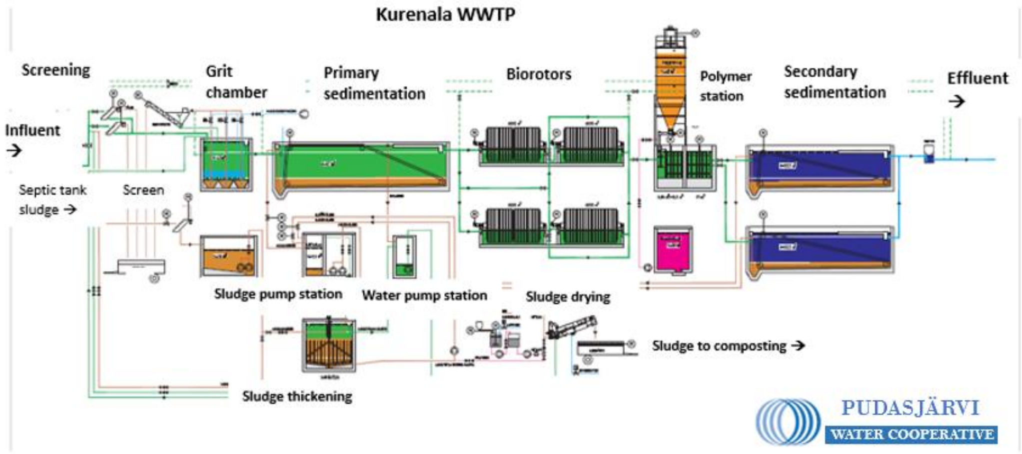


FIGURE 21. Wastewater and sludge treatment process of Kurenala WWTP. (Modified of the figure by Pudasjärvi Vesiosuuskunta 2017)

The rotating biological contactors are fixed-bed reactors which consist of rotating discs. The rotating discs called biorotors (Image 4), are partially rotating submerged in wastewater and partially rotating in the air. In the biological rotating contactor process, nitrogen is removed by nitrification and denitrification. The surface of biorotors provides an attachment site for bacteria and a film of biomass grows on the surface of a biorotor. The air for the microorganism is provided whenever the biorotor rotates alternately out of the wastewater in the air. (Spuhler 2017.)

IMAGE 4. The biorotors of Kurenala WWTP (Kouvo 2017)

The last section of the wastewater treatment process is a secondary treatment in two rectangular basins. In these sedimentation basins, ferrous sulphate is added to precipitate phosphorous and sludge settles to the bottom of the tanks. Treated wastewater is discharged to the Siikalampi pond. (Salmela 2017.)

The first stage of the sludge treatment in Kurenala WWTP is thickening by gravity and the second stage is sludge drying with screw dryer. Finally, the sludge is composted and utilized as a fertilizer. (Salmela 2017.)

Kurenala WWTP also receives sludge from septic tanks, which is treated with thickening, screw dryer and finally composted. Reject water from septic tank sludge is treated with a screen for septic tank sludge before it is pumped to a general wastewater treatment process. (Salmela 2017.)

## 6.2 Wastewater flow

From Kurenala WWTP data of wastewater flows was available by every month in 2016. Wastewater inflow varied from 29 079 $m^3$/month (December) to 57 300 $m^3$/month (April). The average flow was 35 289 $m^3$/month in 2016. (Figure 22)

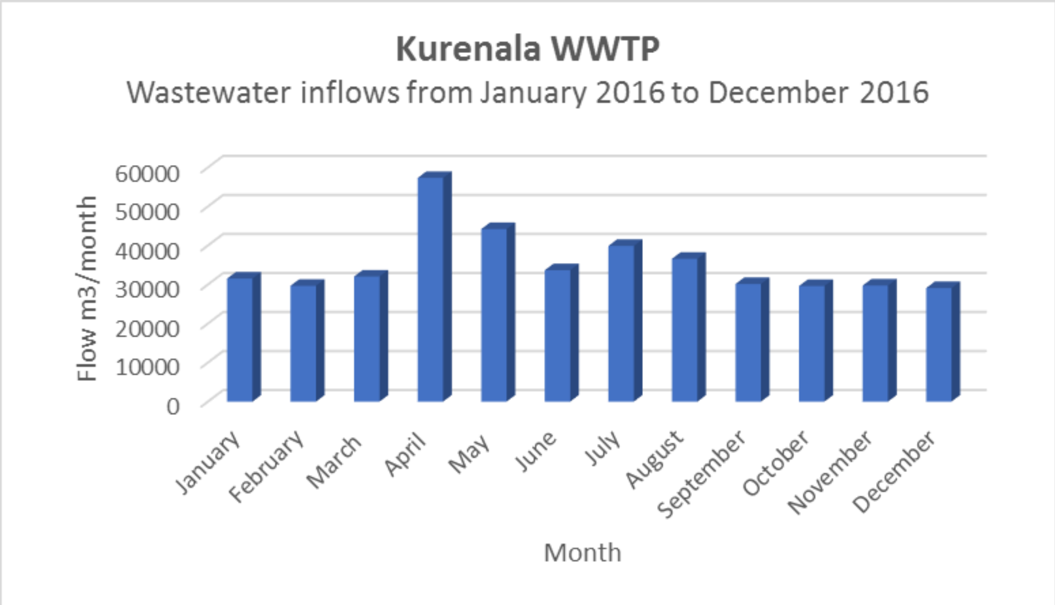


FIGURE 22. Wastewater inflow in Kurenala WWTP in 2016

## 6.3 Loads

Measurements from wastewater loads ($BOD_7$, COD, suspended solids, total nitrogen, total phosphorous) were taken four times by the professional consults from Pöyry Ltd and analyzed in Nablab Ltd laboratory in 2016.

### 6.3.1 $BOD_7$

Compared to Zdroje WWTP, in Kurenala WWTP, BOD is measured in a 7-day period instead of a 5-day period. In order to compare concentrations of $BOD_7$ and $BOD_5$, $BOD_7$ should be converted to $BOD_5$ by dividing $BOD_7$ with 1.15 ($BOD_5 = BOD_7/1.15$) (HELCOM 2017b). In this thesis, loads are not converted to $BOD_5$ because the most important part in loads are the reductions which are same whether they are counted with $BOD_5$ or $BOD_7$.

The influent biological oxygen demand ($BOD_7$) load varied from 252 kg/d to 346 kg/d in 2016. The average load was 292 kg/d. (Figure 23)

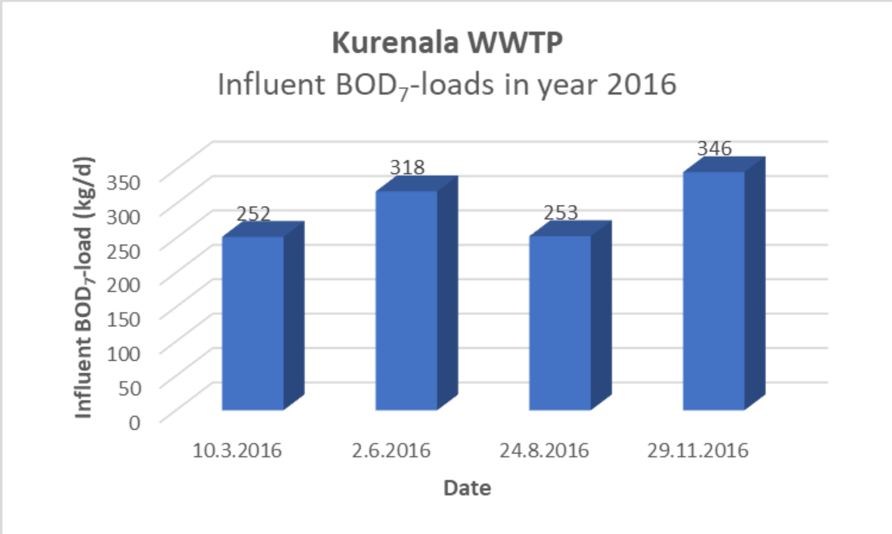


FIGURE 23. Influent $BOD_7$-loads in 2016

The effluent biological oxygen demand ($BOD_7$) load varied from 3.1 kg/d to 13 kg/d in 2016. The average load was 8.95 kg/d. (Figure 24)

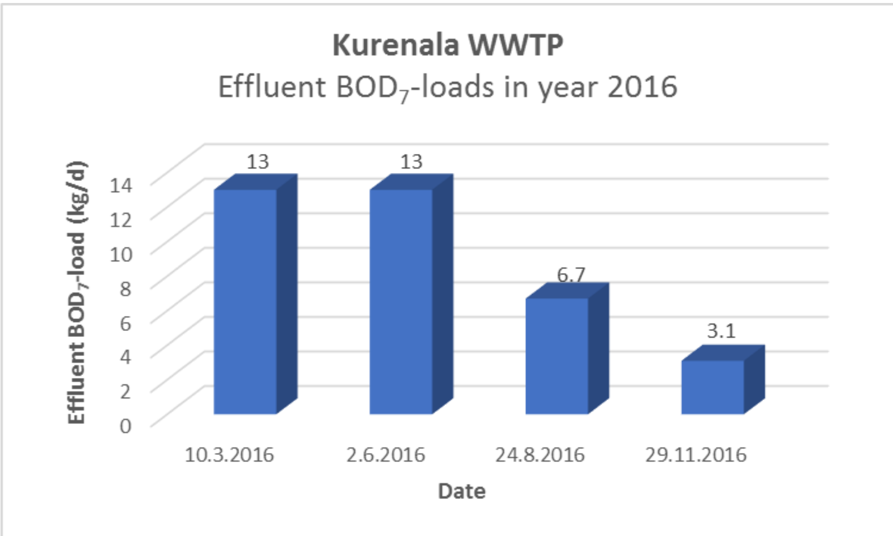


FIGURE 24. Effluent $BOD_7$-loads in 2016

The $BOD_7$ reductions in 2016 are shown in Figure 25. The minimum reduction is almost 95 %. The achieved treatment results fulfil the European Union´s Directive 91/271/EEC requirements (BOD reduction 70-90 %) and the HELCOM recommendations where the minimum percentage of BOD reduction is 80 %

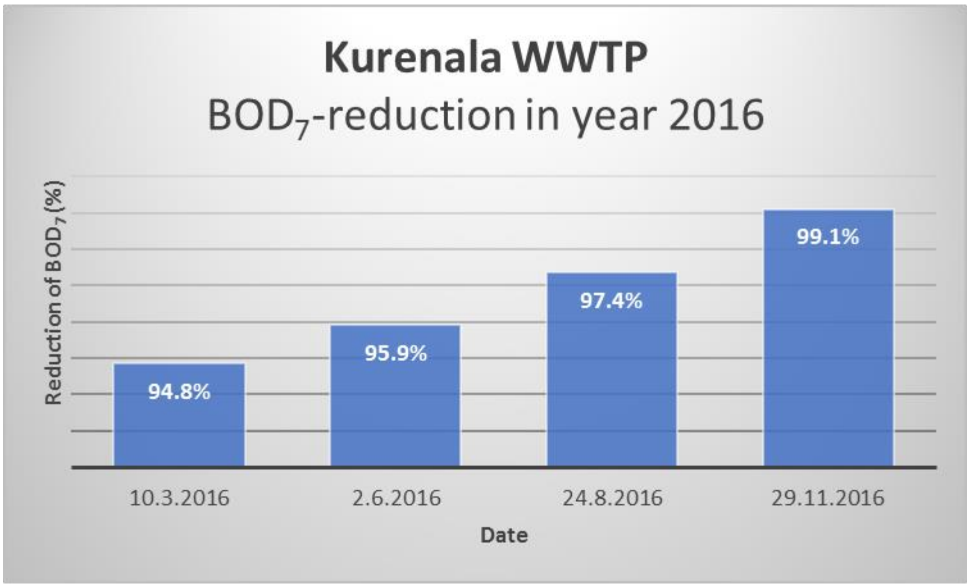


FIGURE 25. Reduction of BOD in 2016

### 6.3.2 COD

The influent chemical oxygen demand (COD) varied from 578 kg/d to 1018 kg/d in 2016. The average load was 784.5 kg/d. (Figure 26)

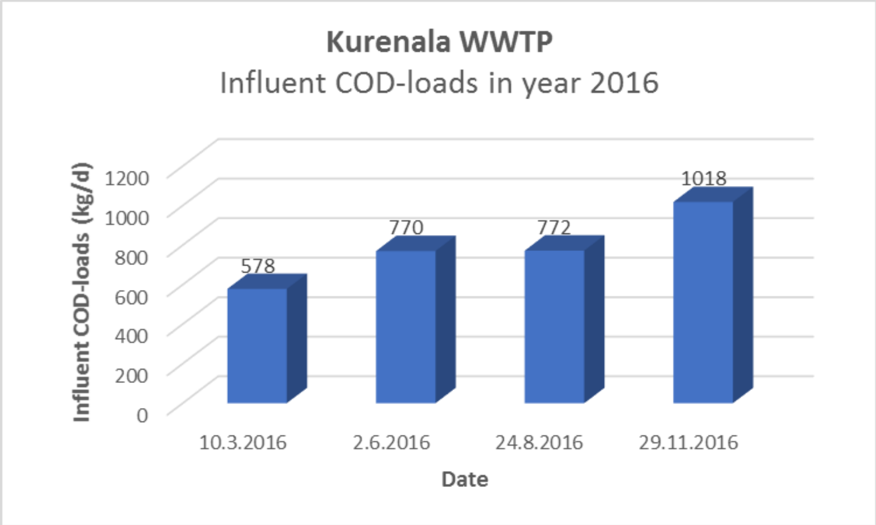


FIGURE 26. Influent COD-loads in 2016

The effluent chemical oxygen demand (COD) varied from 36 kg/d to 46 kg/d in 2016. The average load was 42.25 kg/d. (Figure 27)

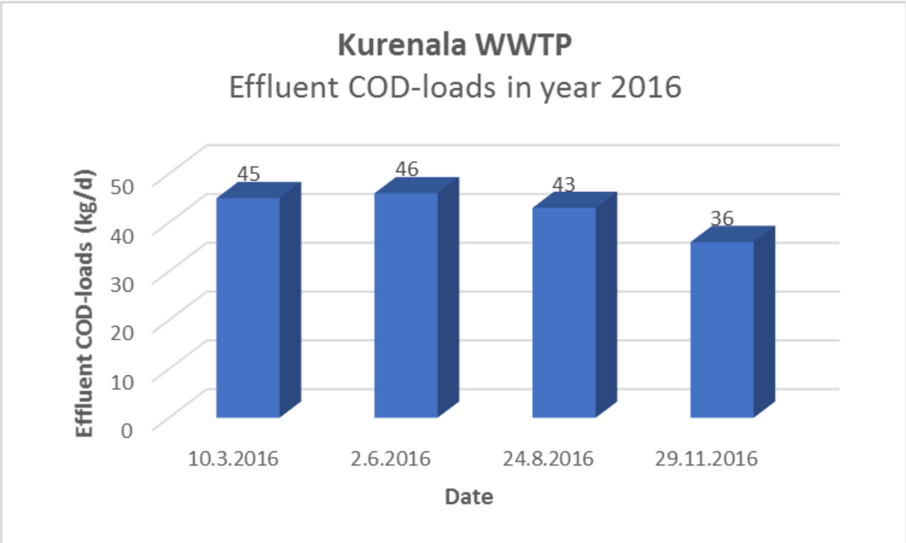


FIGURE 27. Effluent COD-loads in 2016

COD reductions in 2016 are shown in Figure 28. The minimum reduction is around 92 %. The achieved treatment results fulfil the European Union´s Directive 91/271/EEC requirements (COD reduction 75 %). HELCOM does not have recommendations for COD reductions.

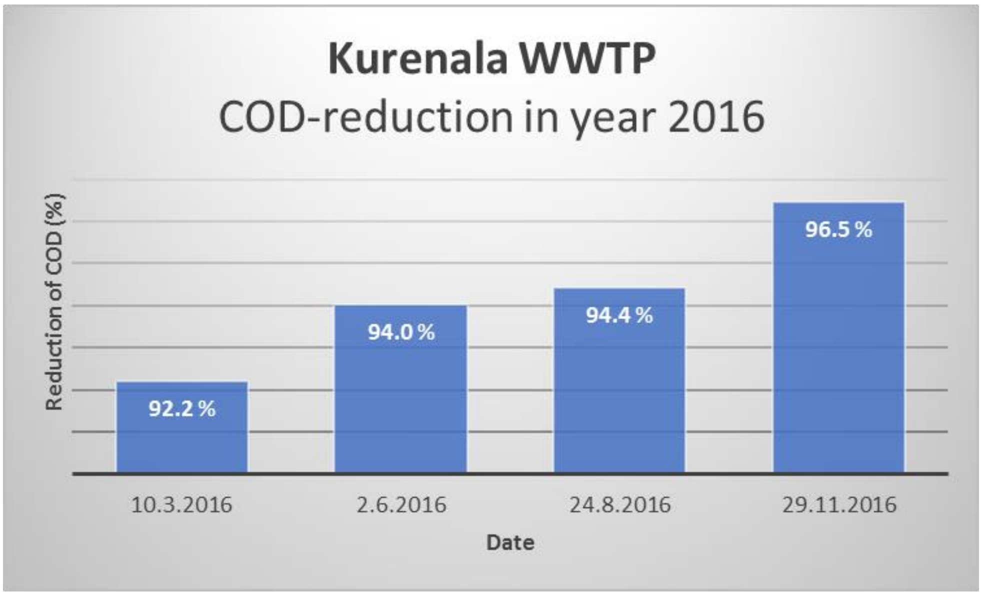


FIGURE 28. Reduction of COD in 2016

### 6.3.3 Suspended solids

The influent suspended solids (SS) loads varied from 364 kg/d to 733 kg/d in 2016. The average load was 605.8 kg/d. (Figure 29)

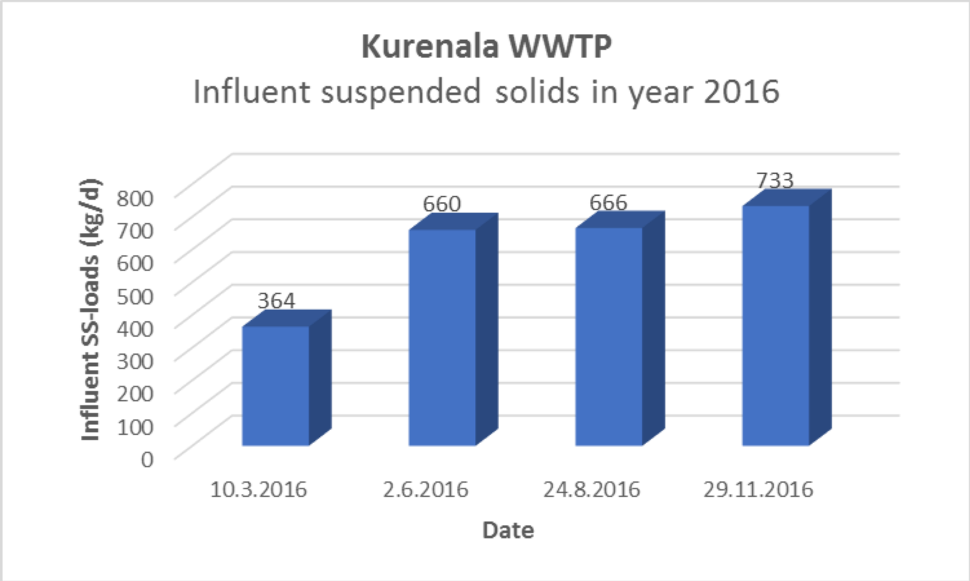


FIGURE 29. Influent suspended solids load in 2016

The effluent suspended solids (SS) loads in 2016 varied from 6.8 kg/d to 25 kg/d. The average load was 13.5 kg/d. (Figure 30)

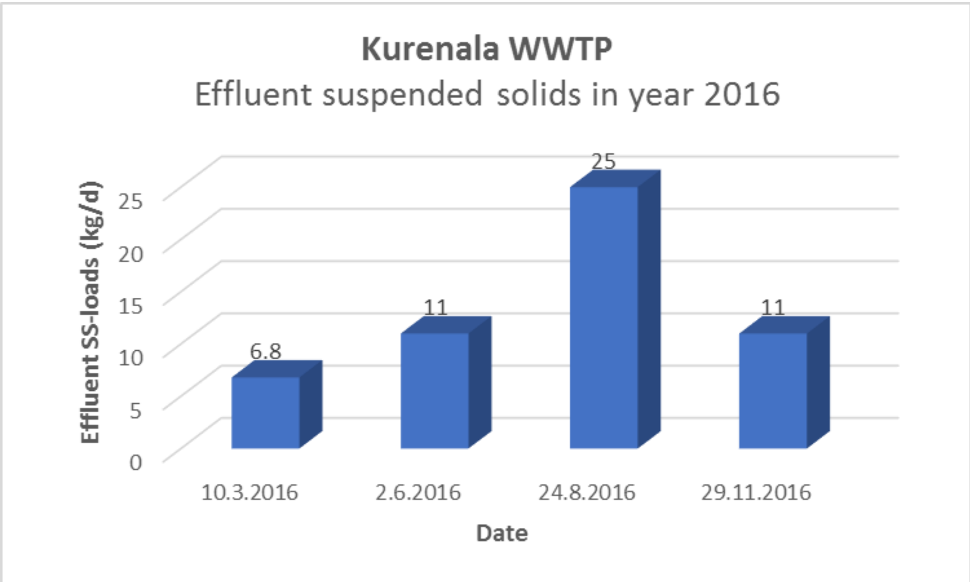


FIGURE 30. Effluent suspended solids in 2016

The suspended solids reductions in 2016 are shown in Figure 31. The minimum reduction is around 96 %. The achieved treatment results fulfil the European Union´s Directive 91/271/EEC requirements for suspended solids (reduction 70 % for 2000-10 000 PE WWTPs). HELCOM does not have recommendations for the suspended solids reduction.

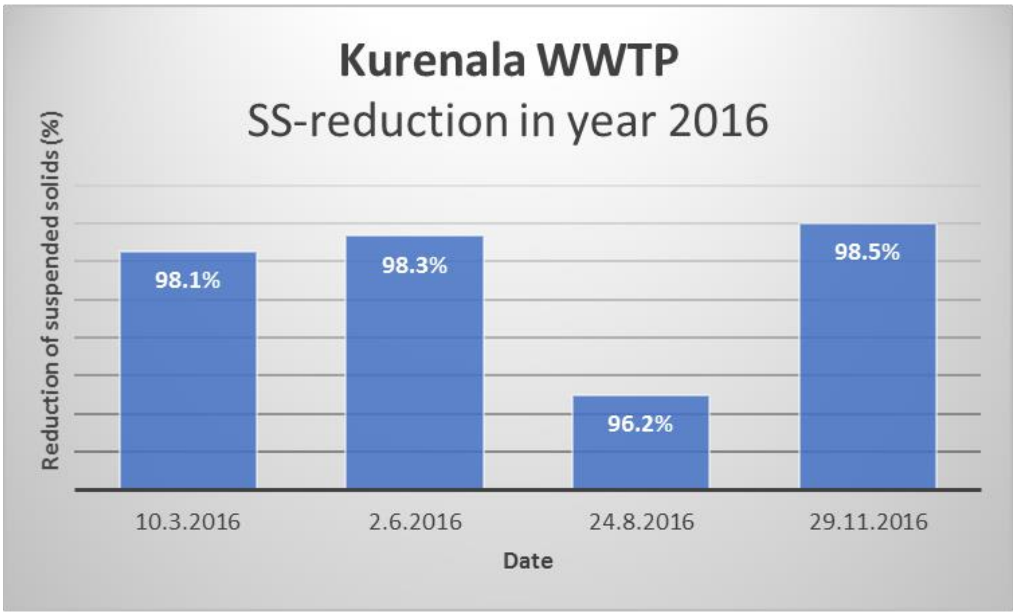


FIGURE 31. Suspended solids reduction in 2016

### 6.3.4 Total nitrogen

The influent total nitrogen loads varied from 60 kg/d to 88 kg/d in 2016. The average load was 75 kg/d. (Figure 32)

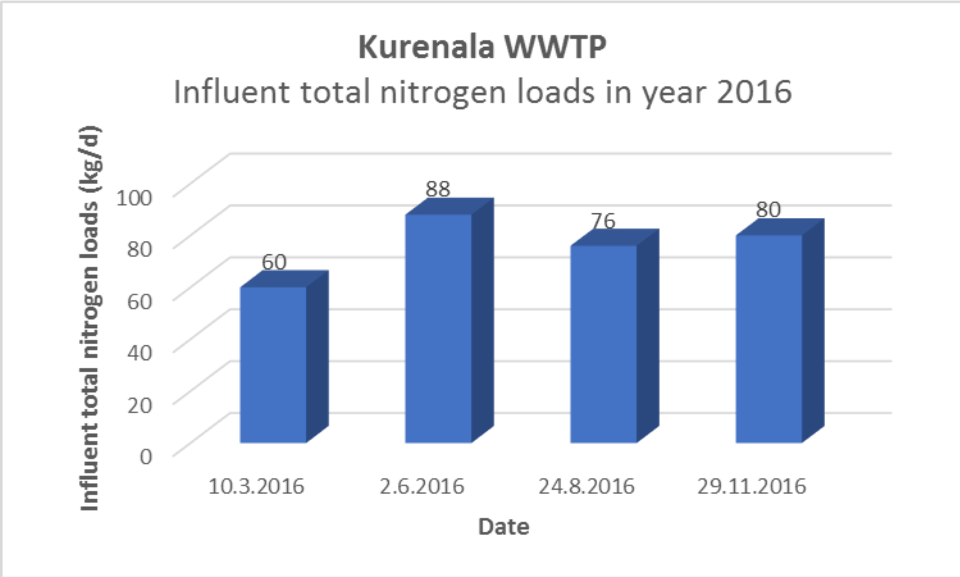


FIGURE 32. Influent total nitrogen loads in 2016

The effluent total nitrogen loads in 2016 varied from 47 kg/d to 55 kg/d. The average load was 49.5 kg/d. (Figure 33)

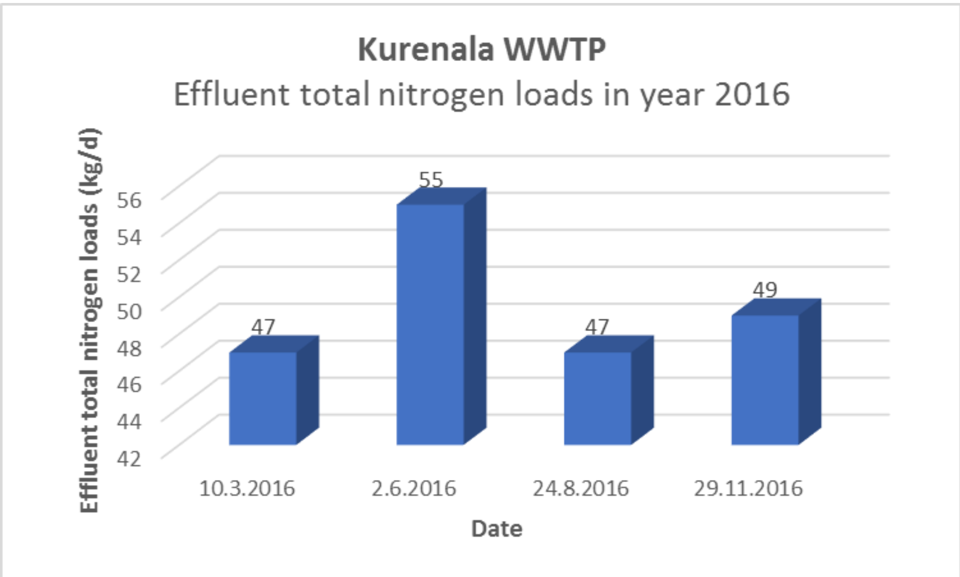


FIGURE 33. Effluent total nitrogen loads in 2016

The total nitrogen reductions in 2016 are shown in Figure 34. The minimum reduction is almost 22 % and maximum reduction almost 39 %. In the European Union´s Directive 91/271/EEC requirements for the total nitrogen concentrations and reductions (reduction 70 – 80 %) are given for over 10 000 PE WWTPs, thus these requirements do not concern Kurenala WWTP (5700 PE).

Three of four total nitrogen measurements do fulfil the HELCOM recommendations where minimum percentage of total nitrogen for WWTPs 2000-10 000 PE reduction is 30 %.

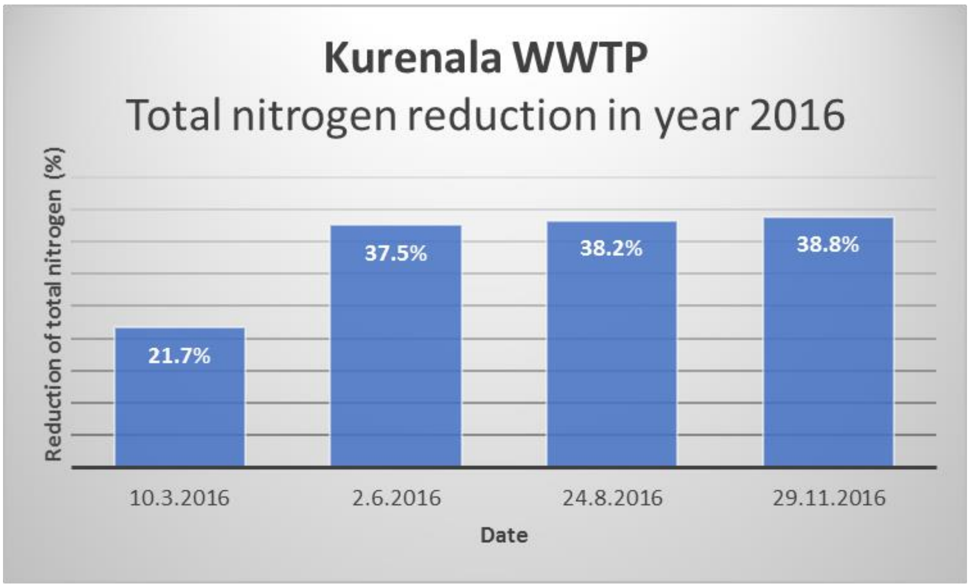


FIGURE 34. Total nitrogen reduction in 2016

### 6.3.5 Total phosphorous

The influent total phosphorous loads in 2016 varied from 9.3 kg/d to 15 kg/d. The average load was 11.8 kg/d. (Figure 35)

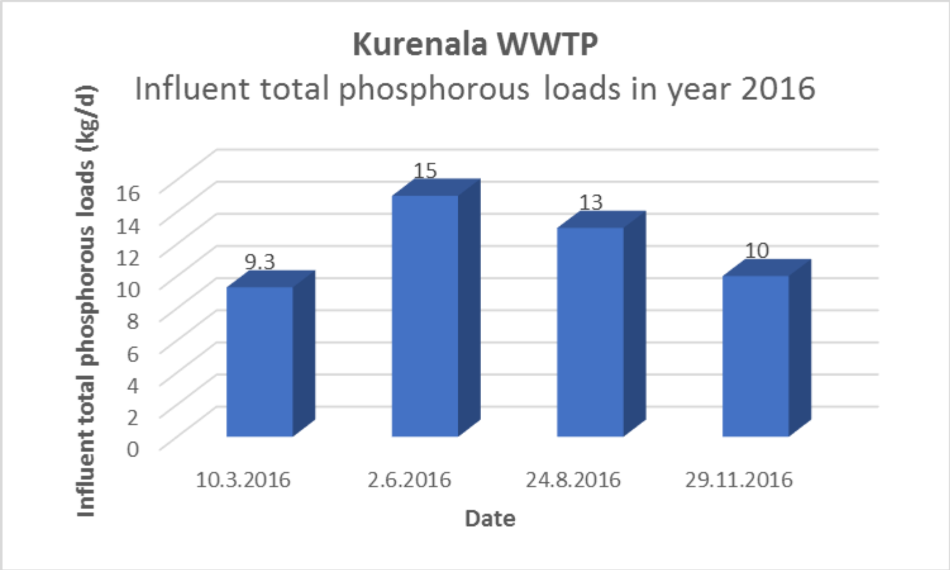


FIGURE 35. Influent total phosphorous loads in 2016

The effluent total phosphorous loads in 2016 varied from 0.071 kg/d to 0.133 kg/d. The average load was 0.103 kg/d. (Figure 36)

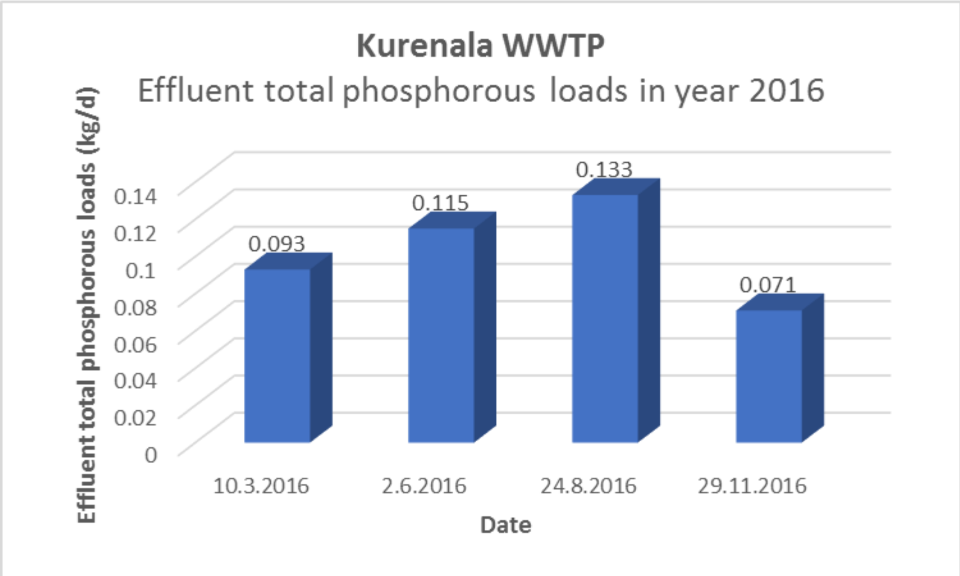


FIGURE 36. Effluent total phosphorous loads in 2016

The total phosphorous reductions in 2016 are shown in Figure 37. The minimum reduction is 99 %. The achieved treatment results fulfil clearly the European Union´s Directive 91/271/EEC requirements for total phosphorous (reduction 80 %) and HELCOM recommendations where minimum percentage of total nitrogen reduction is also 80 %.

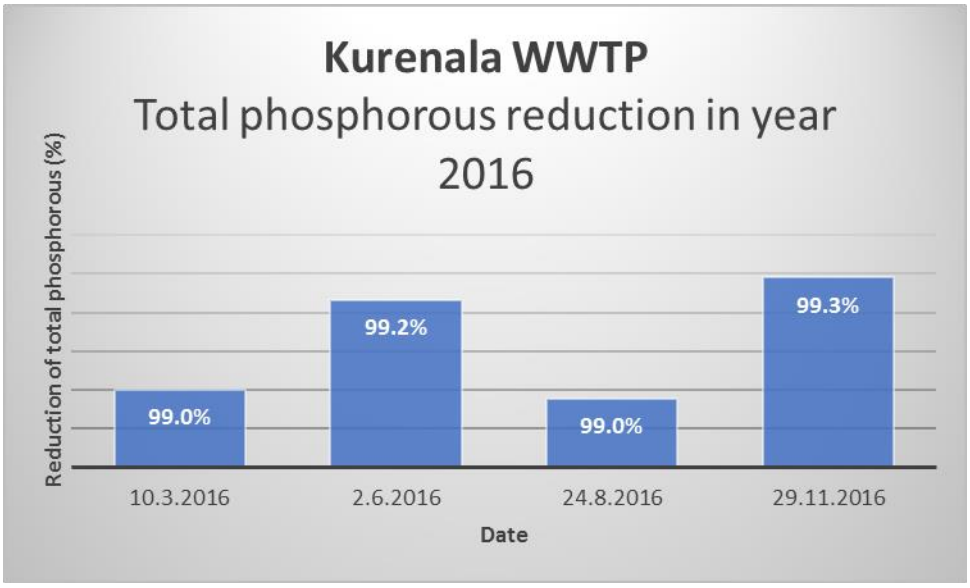


FIGURE 37. Reduction of total phosphorous in 2016

## 6.4 Energy audit in Kurenala WWTP

The energy audit in Kurenala WWTP was executed in July 2017 with a help of the Energy Analysis tool (Appendix 3 & 4). Approximately 35 devices in Kurenala WWTP were considered during the energy audit. In Table 5, it can be seen the number of devices which are divided by different process stages. A more detailed energy consumption of devices is shown in Appendix 4.

TABLE 5. Number of devices in different stage of wastewater and sludge treatment process in Kurenala WWTP

| Process Stage | Number of devices (pcs) |
|---|---:|
| Mechanical cleaning stage | 7 |
| Biological treatment stage | 4 |
| Secondary clarifier | 8 |
| Sludge dewatering | 6 |
| Ventilation | 4 |
| Other | 6 |
| **Total** | **35** |

The first process stage in the energy audit was the mechanical cleaning stage, which includes the motors of the screens and the screen waste pressers, the compressor for the aerated grit chamber, scraper for the primary sedimentation and motor for the sand washer. The second process stage was the biological stage, which includes four rotating biological contactors. The third stage was the secondary clarifier which includes the scrapers for the secondary sedimentation, mixers and shakers for polymer and submersible pumps. The fourth stage was the sludge dewatering with sludge pumps for dewatered sludge, polymer pumps and a screw dryer. The fifth stage was the ventilation stage, which includes blower motors for income, exhaust and transfer air. The sixth stage in Kurenala WWTP was the other stage, which includes a screen for septic tank wastewater, a screen waste presser for septic tank screen waste, sludge pumps for septic tank sludge and pumps for reject water.

According to the energy audit, the electricity consumption in Kurenala WWTP was 312 312 kWh in 2016. Treating cubic wastewater in 2016 consumed energy 0.73 kWh/m$^3$. The highest electricity consumption stage in Kurenala WWTP is the biological stage with a consumption of 29.7 % (~92 800 kWh/a) of total electricity consumption. The second highest electricity consumption represents ventilation with 24.9 % (~77 900 kWh/a) due to Kurenala WWTP location inside a building, in comparison to Zdroje WWTP, which is mostly located outside. The third highest electricity consumption is the secondary sedimentation basin with 18.3 % (~57 000 kWh/a) of total electricity consumption and the fourth highest electricity consuming stage is the mechanical stage 17.7 % (~55 200 kWh/a). The second lowest electricity consumption is in the “other” stage 4.9 % (~15 200 kWh/a), which includes devices for the septic tank sludge and the lowest electricity consumption is the sludge dewatering with 4.5 % (~14 200 kWh/a) of total electricity consumption. (Figure 38)

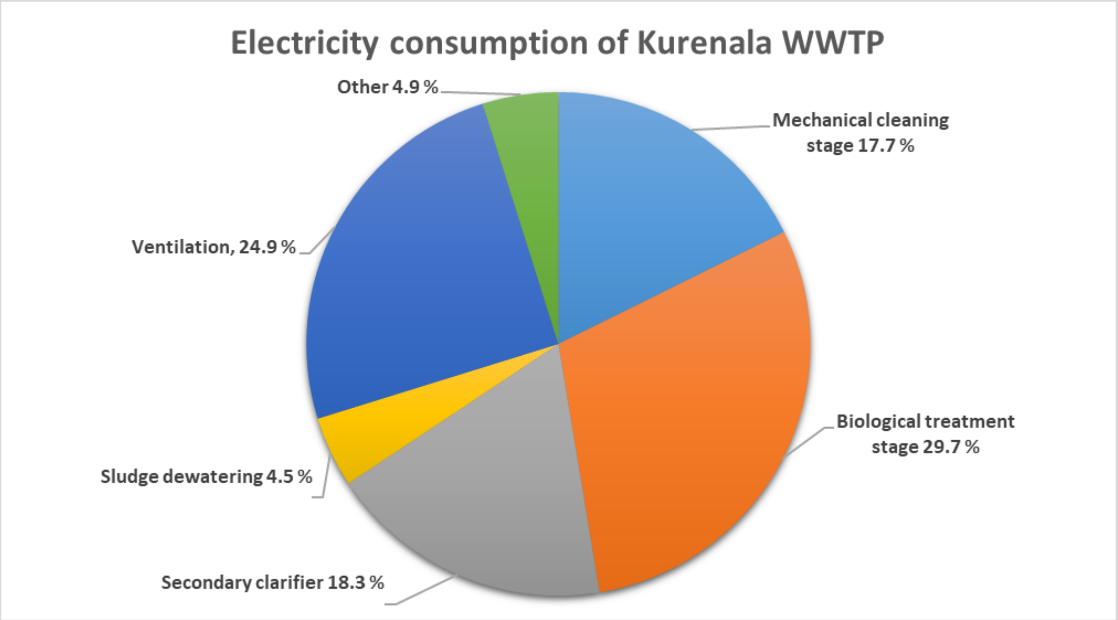


FIGURE 38. Electricity consumption distribution in Kurenala WWTP

# 7 POSSIBILITIES TO IMPROVE ENERGY EFFICIENCY IN WWTPS

The biological stage, especially with aeration, is usually the most energy consuming stage in wastewater treatment plants, as in Zdroje WWTP. At the same time, the biological stage is also the most potential stage to obtain energy savings. By optimizing the biological process, for example, with control systems in an aeration tank, is a huge chance to save energy. Methods for a process optimization can include dissolved oxygen (DO) and ammonium measurements in different parts of the process. According to Antoni & Longo (2016), by DO concentration control, it is possible to save 10-30 % of energy. (Antoni & Longo 2016.) After tested DO control system in Käppala WWTP in Sweden, the total airflow was reduced by 18 % which corresponds with approximately 55 000 € savings per year in the WWTP (Thunberg et al. 2009). The DO concentration in an aeration tank should be maintained to 1.5 to 2 mg/l, a higher concentration of DO may improve nitrification but concentrations over 4mg/l do not improve the treatment, instead the aeration management costs just increase (Au et al 2013). In Zdroje WWTP, the DO- and ammonium measurements are already in use in the biological stage. In order to secure the energy efficiency of a WWTP, it is highly important to maintain and update the needed skills of the employees to monitor and maintain the biological stage (Antoni & Longo 2016).

The bubble size of aerators is important (Mikola 2016). By converting coarse or mechanical aeration to a fine-pore aeration, it is possible to gain 25 % energy savings, and by converting traditional ceramic and elastomeric membrane diffusers to ultra-fine diffusers, energy savings can be 10-20 %. Regular maintenance and cleaning of aerators also reduce the energy costs of aeration. With a help of a monitoring system which help to predict when diffuser air systems require cleaning, it is estimated that energy efficiency could improve 15 %. (Antoni & Longo 2016.)

In a biological stage, the energy efficient compressors are important for energy efficiency. For example, direct-drive, high-speed, turbo blowers can decrease energy demand 35-35 % compared to the conventional blowers. (Antoni & Longo 2016.)

In wastewater treatment plants, generating methane gas from anaerobic digestion of sludge is a huge change to save an external energy use. Gas can be used to heat the digesters, or it can be used in a combined heat and power (CHP) plant unit or even sell the produced power to nearby industries. A CHP unit is already in use in Zdroje WWTP.

An energy consumption in a biological contactor process is lower than in a traditional biological process, such as in an activated sludge process. The only way to effect on energy efficiency in a biological contactor process with biorotors, as in Kurenala WWTP, is the use of energy efficient electric motors, which rotate biorotors. According to the product manager Jari Antikainen from T & A Mämmelä Ltd, energy efficiency in electric motors has enhanced: during the last ten years, the efficiency level of electric motors has developed from the standard efficiency level (IE1) to the premium efficiency level (IE3). (Antikainen 2017.)

If a WWTP is located in a cave or in a building, a ventilation and air conditioning is needed, as in Kurenala WWTP. By operating ventilation and air conditioner equipment more effectively and replacing old devices with more energy efficient and newer systems, energy efficiency can be enhanced, lifetime of equipment extended, and the maintenance costs reduced. According to the U.S department of energy (2017), compared to typical 10-20-year-old systems, the latest ventilation and air conditioning systems can reduce the use of energy. In the newer equipment, the energy efficient ratio (EER) can be up to 11,5; the higher the EER is, the more efficient the units are. Controllers can improve the performance of systems: timers and electronic clocks can reduce the energy use, for example, in WWTP´s offices during the unoccupied periods. By using outside air economizer, which automatically controls air flow, the energy consumption can be minimized, and air quality improved. For example, in the Kurenala WWTP´s biological contactor process, provided air is very important for microbes in the biological process. Maintenance and regular cleaning of ventilation and air conditioning systems are important in order to prevent energy losses caused by dirt. According to the U.S department of energy (2017), regular cleaning of air filters alone can lower the energy use as much as 20 %. (U.S department of energy 2017.)

There are also ways to enhance energy efficiency in motors in wastewater treatment plants. By using energy efficient motors instead of standard motors, energy efficiency can be enhanced by 2-6 % and by using variable-speed drives in motors, it is possible to obtain 50 % savings in energy consumption if the speed of the pump is reduced by 20 %. (Au et al 2013.)

By using the capacitor banks, the power factor of big motors improves. When a power factor improves, the system losses decrease, voltage improves, and the power costs decrease where fees for poor power factor are billed. (Au et al 2013.) According to Tech-Faq (2017), a capacitor bank is a group of several capacitors of the same rating, which are connected in parallel or series to each other, to store electrical energy. To counteract or correct a power factor lag or phase shift in alternating current (AC) power supply, the resulting bank is used. Capacitor banks can also be used in a direct current (DC) power supply to increase the ripple current capacity of the power supply or to increase the overall amount of stored energy. (Tech-Faq 2017.)

Energy saving devices with the load detection monitors installed in series with big motor saves electrical power. These devices monitor electrical load at 380 cycles per second and ensure that optimal power is supplied. Motors should always operate as close to the nameplate voltage as practical; deviations from nameplate voltage of motors effects on efficiency of a motor. It is recommended that a line drop of a motor should not exceed 5 % of the line voltage. To improve energy efficiency of a motor, the right sizing based on the connected load is important. (Au et al 2013.)

# 8 COMPARISON OF ZDROJE WWTP AND KURENALA WWTP

## 8.1 Comparison of electricity consumption

According to the energy audits, the total electricity consumption of Zdroje WWTP in the year 2016 was 2800 MWh (~0.55 kWh/$m^3$ of wastewater) and in Kurenala electricity consumption was 312 MWh (~0.73 kWh/$m^3$ of wastewater). Electricity consumption per cubic meter for wastewater treated is counted by writer of the thesis and methods for counting can be seen in Appendix 5.

Electricity consumption per cubic meter for wastewater treated in the feed pump station in Zdroje WWTP was 0.005 kWh/$m^3$. Comparing this value on the study made by Bodík and Kubaská (2013) (Canada 0.02 kWh/$m^3$ to 0.1 kWh/$m^3$. Hungary 0.0045 kWh/$m^3$ to 0.14 kWh/$m^3$, Australia, the range varies from 0.1 kWh/$m^3$ to 0.37 kWh/$m^3$) the consumption is relative little. In Kurenala WWTP the feed pump stations did not include on the energy audit because stations do not locate at the same area as the treatment plant.

The electricity consumption per cubic meter for wastewater treated in the mechanical stage in Zdroje WWTP was 0.021 kWh/$m^3$ and in Kurenala WWTP it was 0.011 kWh/$m^3$. In the study made by Bodík and Kubaská (2013) it is said that preliminary section consumes relative little energy, which is also the case with Zdroje WWTP and Kurenala WWTP.

The biological treatment stage in Zdroje WWTP consumed electricity per cubic meter for wastewater treated 0.35 kWh/$m^3$ and in Kurenala WWTP 0.02 kWh/$m^3$. In Kurenala this value is much smaller because of the rotating biological contactor process compared to the activated sludge process in Zdroje WWTP. In the study made by Bodík and Kubaská (2013), the electricity consumption of an activated sludge process with nutrient removal in Japan, is 0.39 kWh/$m^3$ to 3.74 kWh/$m^3$. Compared to Zdroje WWTP´s electricity consumption to this this value, the electricity consumption of Zdroje is relative small. Also, electricity consumption of an activated sludge process with oxidation ditch, as in Zdroje WWTP, in the study made by Bodík and Kubaská (2013) the values for electricity consumption are in Australia 0.5 kWh/$m^3$ – 1.0 kWh/$m^3$, in China 0.302 kWh/$m^3$ and in Japan 0.43 kWh/$m^3$ – 2.07 kWh/$m^3$. Electricity consumption of Zdroje WWTP is under these values. In both Zdroje and Kurenala WWTPs, the biological stage is the most electricity consuming stage of the wastewater treatment process, as it is said in literature.

The secondary clarifier stage in Zdroje WWTP consumed electricity per cubic meter for wastewater treated 0.002 kWh/$m^3$ and in Kurenala WWTP 0.011 kWh/$m^3$. This little difference could be because in Kurenala WWTP, the secondary clarification stage includes motors for chemical precipitation by ferrous sulfate which are working 24/7, but in Zdroje WWTP only four motors of secondary clarification scrapers are working all the time and there is no chemical precipitation.

The sludge treatment stage in total (including sludge treatment and sludge dewatering) in Zdroje WWTP consumed electricity per cubic meter for wastewater treated 0.118 kWh/$m^3$ and in Kurenala WWTP 0.003 kWh/$m^3$. This difference is because in Zdroje WWTP sludge is treated with gravity thickeners, drum thickeners and digested in aerobic digestion. This stage in Zdroje WWTP includes much more pumps for sludge, polymer etc. than in Kurenala WWTP has devices in the whole sludge treatment stage. In Kurenala WWTP sludge is treated only with thickening by gravity and dried with a screw dryer and lastly composted and used as a fertilizer.

## 8.2 Comparison reductions of wastewater parameters

The BOD reductions comparison between Zdroje WWTP and Kurenala WWTP is shown in Figure 39. In Figure 39, it can see that all reductions are bit higher in Zdroje WWTP, but the difference is not huge.

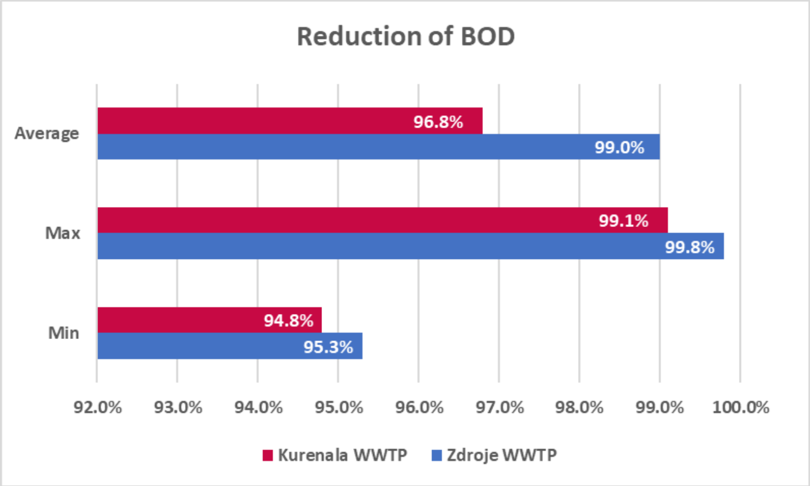


FIGURE 39. Reduction of BOD comparison in 2016

The COD reductions comparison between Zdroje WWTP and Kurenala WWTP is shown in Figure 40. In Figure 40, it visible that the maximum and the average reductions are bit higher in Zdroje WWTP, but the minimum reduction is higher in Kurenala WWTP.

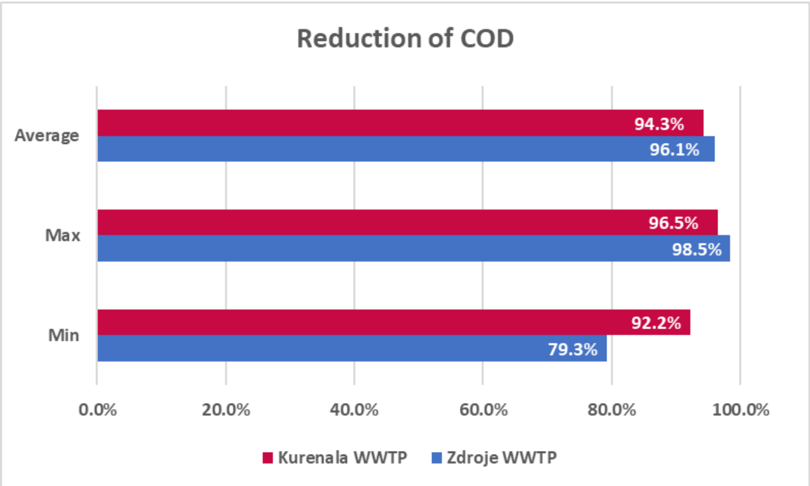


FIGURE 40. Reduction of COD comparison in 2016

The suspended solids reduction comparison between Zdroje WWTP and Kurenala WWTP is indicated in Figure 41. In Figure 41, it can be seen that the minimum reduction was higher in Kurenala WWTP, but the maximum reduction was higher in Zdroje WWTP. The average reduction was a bit higher in Kurenala WWTP.

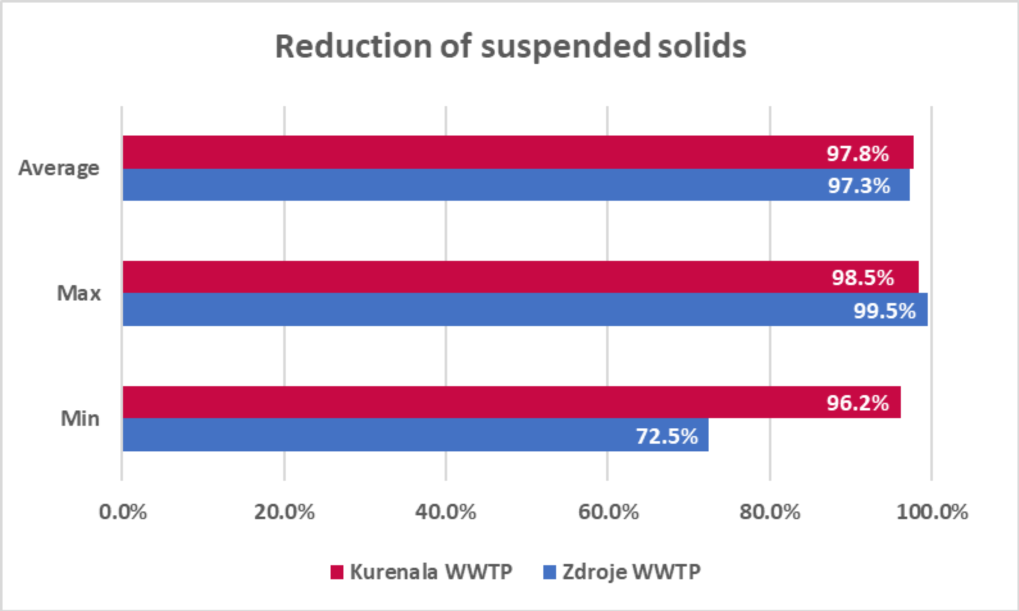


FIGURE 41. Reduction of SS comparison in 2016

The total nitrogen reduction comparison between Zdroje WWTP and Kurenala WWTP is displayed in Figure 42. In Figure 42, it is shown that all reductions are higher in Zdroje WWTP. This difference is due to the fact that, the data received from the Kurenala WWTP indicates that the temperature of the wastewater was under 10°C three times out of four measurements taken during 2016, which has a harmful effect on the nitrification process. Also, there are no requirements for total nitrogen reductions in the Directive 91/271/EEC for wastewater treatment plants under 10 000 PE, such as Kurenala WWTP.

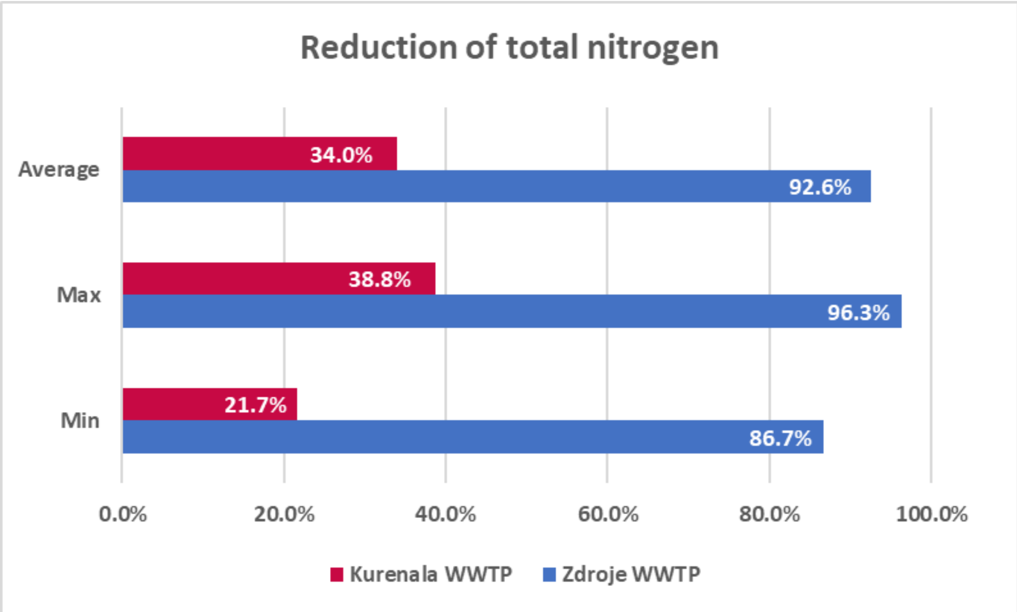


FIGURE 42. Reduction comparison of total nitrogen in 2016

The total phosphorous reduction comparison between Zdroje WWTP and Kurenala WWTP is shown in Figure 43. Figure 43 indicates that all reductions are higher in Kurenala WWTP. The average and maximum reductions are almost the same, even though phosphorous in Kurenala WWTP is removed by chemical precipitation and in Zdroje WWTP by biological P-removal but the minimum reductions are much better in Kurenala WWTP.

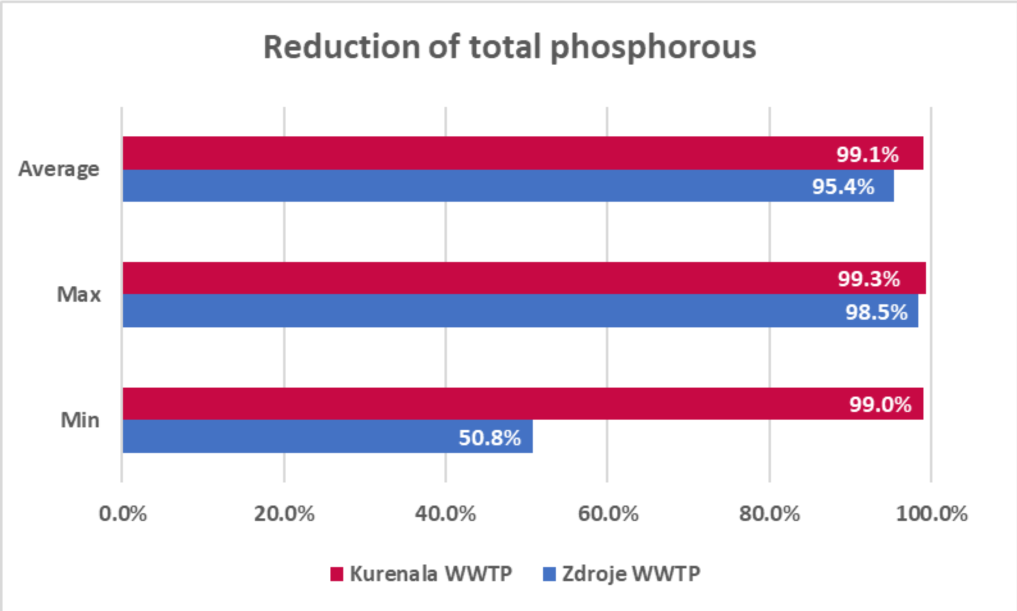


FIGURE 43. Reduction comparison of total phosphorous in 2016

# 9 CONCLUSIONS

Wastewater treatment plants across the world consume huge amounts of energy. With energy audits, it is possible to investigate the energy consumption of a treatment plant and identify the process stages, which consume energy the most. When realizing which stages are the most energy consuming, there is a chance to find ways to save energy. As the main duty of a wastewater treatment plant is to treat wastewater in order to protect people´s health and the environment, it is important that treatment plants do their best to follow the legislation and the recommendations concerning wastewater treatment and wastewater discharges.

The purpose of the study was to examine the electricity consumption of the Zdroje WWTP and the Kurenala WWTP, compare the electricity consumption between the selected treatment plants and literature and finally examine wastewater treatment parameter reduction results. The results were that the Zdroje WWTP consumed electricity about 2800 MWh/a and the Kurenala WWTP 312 MWh/a. The electricity consumption per cubic meter for wastewater treated in the Zdroje WWTP was lower: 0.55 kWh/m$^3$, and higher in the Kurenala WWTP: 0.73 kWh/m$^3$. In both treatment plants, the biological stage consumed the most energy compared to the other treatment stages and when comparing electricity consumption to literature, no big differences were found: the electricity consumption of both plants was on the lowest range of the values given in literature. Both plants fulfilled most of the requirements of the legislation and recommendations concerning wastewater treatment reduction parameters, considering the differences in size, process and location of the WWTPs. In addition, recommendations for the WWTPs most energy consuming treatment stages was introduced in the study.

The main challenges while doing the study was at the beginning, the writer´s lack of knowledge concerning energy audits, lack of knowledge of different kind of wastewater treatment processes and lack of knowledge of the technique (motors, pumps, blowers etc.) used in wastewater treatment plants. Due to the fact, that the Zdroje WWTP was the first and one of the biggest audited wastewater treatment plants during the IWAMA-audits, the audit process itself and information and data evaluation was difficult. Furthermore, due to the different location of Zdroje WWTP in Poland and the writer living in Finland, getting missing information after the audit, was challenging.

However, the required knowledge of the writer improved during the audits, and the last audit in the Kurenala WWTP was easier to conduct. Also, because it was possible to conduct the audit in Finnish it was easier to work with the information and data.

For the IWAMA project, the commissioner of the thesis, one of the main aims was to test and develop the audit concept. The first round of the audits during 2017 was the development and testing step of the Energy Analysis tool and the concept. Now the energy audit concept has been tested and one of the main tools of the audit concept, the Energy Analysis Tool, has been developing during the audits. Developing of the concept continue during IWAMA project and the actual concept is aimed to be ready at the end of the IWAMA project, at the beginning of the year 2019.

For further study could be, for example, specific analysis of Zdroje and Kurenala WWTPs, what kind of individual and specific energy savings these plants could achieve and what kind of energy saving investments the plants could consider. Specific energy saving calculations and reduction calculations on greenhouse gas emissions would be interesting and beneficial to conduct.

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ZWIK. 2016. Image 2: Zdroje wastewater treatment plant

APPENDICES

**APPENDIX 1.** Energy Analysis Tool: Data input, Zdroje WWTP

**2.) general operating data:**

| | | | |
|---|---|---|---|
| $Q_d$: | 14,353.00 | [m³/d] | mean daily wastewater inflow |
| $B_{d,COD,aM}$: | 9,774.00 | [kg/d] | annual average of daily COD-load in inflow |
| $E_{ext}$: | 3,475,185.00 | [kWh/a] | total purchased electricity (data from bill by energy supply company) |

**3.) feed pump stations:**

| | | |
|---|---|---|
| feed pump station existing? | yes | |
| different boundary conditions? | no | e.g. different kind of pumps, delivery head $h_{geod}$, pumped wastewater volume Q |

*feed pump station 1* — **f. pump 1**

| | | | |
|---|---|---|---|
| kind of pump: | | centrifugal pump | |
| vortex vacuum gear/single vane: | | vortex vacuum gear | |
| number of pumps/lifting equipments: | | 4 | |
| wastewater delivered: | Q = | 5,316,745.00 | [m³/a] |
| delivery head: | $h_{deli}$ = | 12.30 | [m] |
| - friction losses: | $h_v$ = | 2.20 | [m] |

**4.) mechanical cleaning stage:**

a) grid rack and screening plant: — **screen**

| | | |
|---|---|---|
| number of aggregates: | 13 | The number of aggregates includes in this case the number of coarse racks/fine screens or sieve machines as well as aggregates like screening presses etc. |

b) grit chamber/grease trap:

| | | | |
|---|---|---|---|
| number of scrapers: | 8 | | **scraper** |
| number of aeration units: | 2 | | **aeration** |
| - volume of grit chamber: $V_{SF}$ = | 100.00 | [m³] | number of tanks: 2 |

| | | | | |
|---|---|---|---|---|
| - blow-in depth: | $h_d$ = | 2.50 | [m] | |
| - friction losses: | $h_V$ = | 0.30 | [m] | |
| - efficiency air blower: | $\eta_{blower}$ = | 0.70 | [-] | |

c) primary settlement tank: **pr.se.tank**

number of scrapers: 12

d) pump stations:

pump station existing in mechanical cleaning stage? no — e.g. pumps for primary sludge

d) other aggregates in mechanical cleaning stage **other**

number of aggregates: 2 — e.g. grit washing system, grit classifier etc.

## 5.) biological treatment stage:

| cleaning process: | | | |
|---|---|---|---|
| | - activated sludge | ☑ | Select the existing cleaning process. Multiple selection is possible. |
| | - trickling filter | ☐ | |
| | - membrane bioreactor | ☐ | |

**activated sludge:**

a) operating data aeration:

| | | | |
|---|---|---|---|
| $T_{BB}$: | 18.79 | [°C] | wastewater temperature in aeration tank |
| $t_{TS}$: | 63 | [d] | sludge age |

*inflow aeration tank:*

| | | | |
|---|---|---|---|
| $C_{COD,ZB}$: | 617.18 | [mg/l] | COD-concentration in the inflow of the aeration tank |
| $C_{BOD,ZB}$: | 414.55 | [mg/l] | $BOD_5$-concentration in the inflow of the aeration tank |
| $C_{N,ZB}$: | 106.08 | [mg/l] | N-concentration in the inflow of the aeration tank |
| $S_{NO3,ZB}$: | 0.17 | [mg/l] | $NO_3$-concentration in the inflow of the aeration tank |

*outflow secondary sedimentation:*

| | | | |
|---|---|---|---|
| $S_{orgN,AN}$: | 1.93 | [mg/l] | organic nitrogen in the outflow of the secondary clarifier |
| $S_{NO3,AN}$: | 2.23 | [mg/l] | nitrate nitrogen in the outflow of the secondary clarifier |

b) aeration:

| | | | |
|---|---|---|---|
| kind of aeration | - surface aeration | no | Mark the relevant aeration systems with "yes". Multiple selection possible. |
| | - pressure aeration | yes | |

- *pressure aeration:* **pres.aer.**

system: area-wide aeration

number of aeration aggregates: 5

blow-in depth $h_{d,D}$: 4.85 [m]

c) agitators/turnover: **agit.**

(denitrification, anaerobic tank)

number of agitators: 12

volume of turned tank: 12,944.0 [m³]

d) return activated sludge pumps:

different boundary conditions? no e.g. different kind of pumps, delivery head, delivered wastewater volume

*pump station 1* **ret.pu. 1**

kind of pump: other

number of pumps: 2

ert amount of sludge delivered: Q = 21,149.82 [m³/a]

delivery head: $h_{deli}$ = 1.60 [m]

- friction losses: $h_v$ = 0.40 [m]
- hydraulic efficiency of pump: $\eta_{pump}$ = 0.75 [-]
- efficiency of motor: $\eta_{motor}$ = 0.88 [-]

e) other pump stations:

other pump stations existing? no e.g. recirculation pumps etc.

f) other aggregates: **B_other**

number of other aggregates: 0

**other pump stations:**

other pump stations existing in the biological stage? no

**other aggregates in biological treatment stage:** **Bio_other**

number of other aggregates: 0

## 6.) secondary clarifier:

a) scraper:

number of scrapers: 4 **SC_scra.**

b) pumps for the excess sludge:

different boundary conditions? no e.g. different kind of pumps, delivery head, delivered wastewater volume

*pump station 1* **SC_PS1**

kind of pump: centrifugal pump

- multi-vane/spiral gear: multi-vane

number of pumps: 2

amount of sludge delivered: Q = 74,590.00 [m³/a]

delivery head: $h_{deli}$ = 4.70 [m]

- friction losses: $h_v$ = 2.30 [m]

c) other aggregates: **SC_other**

number of other aggregates 4

## 8.) sludge treatment:

a) surplus sludge thickening: **ST_thick.**

number of aggregates: 15

kind of process: raveling screen/rotary scree

amount of surplus sludge: $Q_{ÜS}$ = 122,421.00 [m³/a]

b)sludge digestion: **ST_digest.**

number of aggregates: 8 e.g. rabble rakes, heating sludge pumps, circulation pumps etc.

amount of digested sludge: $Q_{FS}$ = 54,881.40 [m³/a]

## 9.) sludge dewatering:

a) digested sludge dewatering: **SE_FSE**

number of aggregates: 2 — inclusively pumps for the dosage of polymers (if excisting)

kind of process: high-performance centrifuge

amount of digested sludge: $Q_{FS}$ = 54,881.40 [m³/a]

b) desintegration (ultrasound): **SE_Desint**

number of aggregates: 0

c) primary-sludge sieving: **SE_PS-S**

number of aggregates: 0

c) turnover of digestion tank: **ST_turno.**

number of aggregates: 1 — e.g. screw pumps, external pumps

volume of digestion tank: $V_{FB}$ = 3,750.00 [m³]

d) other aggregates: **ST_other**

number of other aggregates: 4

## 10.) exhaust air cleaning

number of aggregates: 0 **exh. air**

air exchange: $Q_L$ = 108 [1000m³/d] — total value of all plant components

d) other aggregates: **SE_Sonst**

number of other aggregates: 10

## 11.) cogeneration plant

cogeneration plant existing? yes

a) electricity generation: yes

$E_{KWK,el}$ = 126,912.00 [kWh/a] annual electricity generation of cogeneration unit plus energy equivalents from directly operated aggregates

$N_{KWK}$ = 90.00 [%] proportion of digester gas converted into electricity

*kind of cogeneration unit:* micro gasturbine

size: 238 [kWel] electric power of cogeneration unit

$E_{FG}$ = 7,884,292.00 [kWh/a] net calorific value of digester gas production (absolute)

b) heat generation: yes

$E_{KWK,th}$ = 2,483,551.98 [kWh/a] annual heat generation of cogeneration unit

$N_{KWK}$ = 90.00 [%] proportion of digester gas converted into heat

*kind of cogeneration unit:* micro gasturbine

size: 321 [kWel] electric power of cogeneration unit

$E_{FG}$ = 7,884,292.00 [kWh/a] net calorific value of digester gas production (absolute)

## 12.) heat consumption

a) total heat consumption:

$E_{th}$ = 12,361,920.00 [kWh/a] total heat consumption (heat production from cogeneration + supply with external heat)

b) external heat consumption:

heat supplied by third parties/external? yes

energy carrier: heating oil

$Q_{primary\ energy\ carrier}$: 100,800.00 [l/a]

c) sludge treatment:

sludge digestion excisting? yes

- *sludge heating:*

| | | | |
|---|---|---|---|
| amount of raw sludge: | $Q_{RS}$ = | 54,881.40 | [m³/a] |
| difference in temperature: | $\Delta T$ = | 21.0 | [K] |
| thermal efficiency: | $\eta_{th}$ = | 0.70 | [-] |

- *transmission losses of digestion tank:*

| | | | |
|---|---|---|---|
| surface of digestion tank: | A = | 1,350.00 | [m²] |

d) transmission losses of premises:

| | | | |
|---|---|---|---|
| effective area: | A = | | [m²] |
| heat consumption: | $E_{th,BG}$ = | 2,130,720.00 | [kWh/a] |

## 13.) other

number of other aggregates: 1

**other**

**APPENDIX 2.** Energy Analysis Tool: Consumption list, Zdroje WWTP

## Energy analysis of clarification plants

list of consumers

plant name: WWTP Zdroje — year of data collection: 2016

| consumer | group | year of construction | system code | motor data: nominal voltage [V] | cosφ [-] | installed power [kW] | efficiency category [-] | frequency converter [-] | connected value: electricity actual state [A] | efficiency [%] | power calculated [kW] | duration time [h/a] | annual consumption [kWh/a] | fix value | proportion [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **feed pump stations** | | | | | | | | | | | | | refresh | | |
| feed pump 1 | f. pump 1 | 2007 | P1-A | 400 | 0.78 | 35.00 | EFF2 | no | | 91.4 | 38.29 | 2200 | 67,396.06 | | 2.39 |
| feed pump 2 | f. pump 1 | 2007 | P1-B | 400 | 0.78 | 35.00 | EFF2 | no | | 91.4 | 38.29 | 2200 | 67,396.06 | | 2.39 |
| feed pump 3 | f. pump 1 | 2007 | P1-C | 400 | 0.78 | 35.00 | EFF2 | no | | 91.4 | 38.29 | 2200 | 67,396.06 | | 2.39 |
| feed pump 4 | f. pump 1 | 2007 | P1-D | 400 | 0.78 | 35.00 | EFF2 | no | | 91.4 | 38.29 | 2200 | 67,396.06 | | 2.39 |
| **sum:** | | | | | | **140.00** | | | | | **153.17** | | **269,584.25** | | **9.58** |
| **mechanical cleaning stage** | | | | | | | | | | | | | refresh | | |
| coarse screen motor 1 | screen | 2015 | K01-B | 400 | 0.86 | 0.55 | IE1 | no | | 72.1 | 0.76 | 1460 | 890.98 | | 0.03 |
| coarse screen conveyer 1 | screen | | | 230 | 0.80 | 3.00 | EFF2 | no | | 82.6 | 3.63 | 1460 | 4,242.13 | | 0.15 |
| coarse screen motor 2 | screen | | K02 | 400 | 0.86 | 0.55 | IE1 | no | | 72.1 | 0.76 | 1460 | 890.98 | | 0.03 |
| coarse screen conveyer 2 | screen | | | 230 | 0.80 | 3.00 | EFF2 | no | | 82.6 | 3.63 | 1460 | 4,242.13 | | 0.15 |
| fine screen motor 1 | screen | | K02-C | 230 | 0.85 | 4.00 | EFF2 | no | | 84.2 | 4.75 | 1460 | 5,548.69 | | 0.20 |
| fine screen conveyer 1 | screen | | C01-C | 400 | 0.83 | 2.20 | IE1 | no | | 79.7 | 2.76 | 1460 | 3,224.09 | | 0.11 |
| fine screen motor 2 | screen | | K02-B | 230 | 0.85 | 4.00 | EFF2 | no | | 84.2 | 4.75 | 1460 | 5,548.69 | | 0.20 |
| fine screen conveyer 2 | screen | | C01-B | 400 | 0.83 | 2.20 | IE1 | no | | 79.7 | 2.76 | 1460 | 3,224.09 | | 0.11 |
| fine screen motor 3 | screen | | K02-A | 230 | 0.85 | 4.00 | EFF2 | no | | 84.2 | 4.75 | 1460 | 5,548.69 | | 0.20 |
| fine screen conveyer 3 | screen | | C01-A | 400 | 0.83 | 2.20 | IE1 | no | | 79.7 | 2.76 | 1460 | 3,224.09 | | 0.11 |
| sand classifier mixer | screen | | M10 | 400 | 0.75 | 0.37 | IE1 | no | | 72.1 | 0.51 | 1460 | 599.39 | | 0.02 |
| sand classifier conveyer | screen | | C02 | 400 | 0.86 | 0.43 | IE1 | no | | 72.1 | 0.60 | 1460 | 696.59 | | 0.02 |
| sand classifier valve | screen | | | 400 | 0.86 | 0.75 | IE1 | no | | 72.1 | 1.04 | 1460 | 1,214.98 | | 0.04 |
| scraper movement motor 1.1 | scraper | | Z1-B | 400 | 0.66 | 0.18 | IE1 | no | | 72.1 | 0.25 | 8700 | 1,737.59 | | 0.06 |
| scraper movement motor 1.2 | scraper | | | 230 | 0.79 | 0.21 | IE1 | no | | 72.1 | 0.29 | 8700 | 2,027.18 | | 0.07 |
| scraper movement motor 2.1 | scraper | | Z1-A | 400 | 0.66 | 0.18 | IE1 | no | | 72.1 | 0.25 | 8700 | 1,737.59 | | 0.06 |
| scraper movement motor 2.2 | scraper | | | 230 | 0.79 | 0.21 | IE1 | no | | 72.1 | 0.29 | 8700 | 2,027.18 | | 0.07 |
| grit removal pump 1 | scraper | | P1-B | 400 | 0.86 | 0.50 | IE1 | no | | 72.1 | 0.69 | 8700 | 4,826.63 | | 0.17 |
| grit removal pump 2 | scraper | | P1-A | 400 | 0.86 | 0.50 | IE1 | no | | 72.1 | 0.69 | 8700 | 4,826.63 | | 0.17 |
| grease removal pump 1 | scraper | | P2-B | 400 | 0.86 | 1.30 | IE1 | no | | 75.0 | 1.73 | 0 | 0.00 | | 0.00 |
| grease removal pump 2 | scraper | | P2-A | 400 | 0.86 | 1.30 | IE1 | no | | 75.0 | 1.73 | 0 | 0.00 | | 0.00 |
| grit chamber blower motor | aeration | | D1-A | 400 | 0.88 | 3.00 | EFF1 | no | | 86.7 | 3.46 | 4500 | 12,456.75 | | 0.44 |
| grit chamber blower motor | aeration | | D1-B | 400 | 0.88 | 3.00 | EFF1 | no | | 86.7 | 3.46 | 4500 | 12,456.75 | | 0.44 |
| tipping trough motor 1 | pr.se.tank | | L1-A | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 1460 | 291.60 | | 0.01 |
| scraper motor 1 | pr.se.tank | | Z2-A | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 8700 | 1,737.59 | | 0.06 |
| tipping trough motor 2 | pr.se.tank | | L1-B | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 1460 | 291.60 | | 0.01 |
| scraper motor 2 | pr.se.tank | | Z2-B | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 8700 | 1,737.59 | | 0.06 |
| tipping trough motor 3 | pr.se.tank | | L1-C | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| scraper motor 3 | pr.se.tank | | Z2-C | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| tipping trough motor 4 | pr.se.tank | | L1-D | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| scraper motor 4 | pr.se.tank | | Z2-D | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| tipping trough motor 5 | pr.se.tank | | L1-E | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| scraper motor 5 | pr.se.tank | | Z2-E | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| tipping trough motor 6 | pr.se.tank | | L1-F | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| scraper motor 6 | pr.se.tank | | Z2-F | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 0 | 0.00 | | 0.00 |
| biofilter 1 | other | 2009 | B1 | 400 | 0.82 | 1.50 | IE1 | no | | 77.2 | 1.94 | 8700 | 13,523.32 | | 0.48 |
| biofilter 3 | other | | B3 | 400 | 0.80 | 0.75 | IE1 | no | | 72.1 | 1.04 | 8700 | 7,239.94 | | 0.26 |
| **sum:** | | | | | | **42.04** | | | | | **52.31** | | **106,013.46** | | **3.77** |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **biological treatment stage** | | | | | | | | | | | | | refresh | | |
| aeration aggregate 1 | pres.aer. | | D3-A | 400 | 0.87 | 160.00 | IE1 | no | | 93.8 | 170.58 | 2950 | 402,558.64 | | 14.30 |
| aeration aggregate 2 | pres.aer. | | D3-B | 400 | 0.87 | 160.00 | IE1 | no | | 93.8 | 170.58 | 2950 | 402,558.64 | | 14.30 |
| aeration aggregate 3 | pres.aer. | | D3-C | 400 | 0.87 | 160.00 | IE1 | no | | 93.8 | 170.58 | 2950 | 402,558.64 | | 14.30 |
| valve motor 1 | pres.aer. | | ZZ04 | 400 | 0.86 | 0.00 | IE1 | no | | 0.0 | 0.00 | 0 | 0.00 | | 0.00 |
| valve motor 2 | pres.aer. | | ZZ05 | 400 | 0.86 | 0.00 | IE1 | no | | 0.0 | 0.00 | 0 | 0.00 | | 0.00 |
| pre-mixing motor 1 | agit. | | M2-A | 400 | 0.86 | 3.50 | IE1 | no | | 81.5 | 4.29 | 8760 | 30,095.71 | | 1.07 |
| pre-mixing motor 2 | agit. | | M2-B | 400 | 0.86 | 3.50 | IE1 | no | | 81.5 | 4.29 | 8760 | 30,095.71 | | 1.07 |
| pre-mixing motor 3 | agit. | | M3-A | 400 | 0.86 | 4.50 | IE1 | no | | 83.1 | 5.42 | 8760 | 37,949.46 | | 1.35 |
| pre-mixing motor 4 | agit. | | M3-B | 400 | 0.86 | 4.50 | IE1 | no | | 83.1 | 5.42 | 8760 | 37,949.46 | | 1.35 |
| sum: | | | | | | **583.00** | | | | | **632.00** | | **1,820,097.38** | | **64.65** |
| **secondary clarifier** | | | | | | | | | | | | | refresh | | |
| scraper motor 1.1 | SC_scra. | | Z3-A | 400 | 0.75 | 0.12 | IE1 | no | | 72.1 | 0.17 | 8700 | 1,158.39 | | 0.04 |
| scraper motor 1.2 | SC_scra. | | X1-A | 400 | 0.75 | 0.12 | IE1 | no | | 72.1 | 0.17 | 8700 | 1,158.39 | | 0.04 |
| scraper motor 2.1 | SC_scra. | | Z3-B | 400 | 0.75 | 0.12 | IE1 | no | | 72.1 | 0.17 | 8700 | 1,158.39 | | 0.04 |
| scraper motor 2.2 | SC_scra. | | X1-B | 400 | 0.75 | 0.12 | IE1 | no | | 72.1 | 0.17 | 8700 | 1,158.39 | | 0.04 |
| excess sludge pump 1 | SC_PS1 | | P2-A | 400 | 0.86 | 1.60 | IE1 | no | | 77.2 | 2.07 | 1460 | 2,420.73 | | 0.09 |
| excess sludge pump 2 | SC_PS1 | | P2-B | 400 | 0.86 | 1.60 | IE1 | no | | 77.2 | 2.07 | 1460 | 2,420.73 | | 0.09 |
| brush drive motor 1 | SC_other | | L2-A | 400 | 0.86 | 0.55 | IE1 | no | | 72.1 | 0.76 | 365 | 222.75 | | 0.01 |
| brush drive motor 2 | SC_other | | L2-B | 400 | 0.86 | 0.55 | IE1 | no | | 72.1 | 0.76 | 365 | 222.75 | | 0.01 |
| tipping trough motor 1 | SC_other | | P1-A | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 1460 | 291.60 | | 0.01 |
| tipping trough motor 2 | SC_other | | P1-B | 400 | 0.86 | 0.18 | IE1 | no | | 72.1 | 0.25 | 1460 | 291.60 | | 0.01 |
| sum: | | | | | | **5.14** | | | | | **6.84** | | **10,503.70** | | **0.37** |
| **sludge treatment** | | | | | | | | | | | | | refresh | | |
| stirrer motor storage tank | ST_thick. | | M5 | 400 | 0.86 | 6.50 | IE1 | no | | 84.70 | 7.67 | 0 | 0.00 | | 0.00 |
| pump 1 storage tank | ST_thick. | | P1-A | 400 | 0.86 | 1.00 | IE1 | no | | 72.10 | 1.39 | 0 | 0.00 | | 0.00 |
| pump 2 storage tank | ST_thick. | | P1-B | 400 | 0.86 | 1.00 | IE1 | no | | 72.10 | 1.39 | 0 | 0.00 | | 0.00 |
| motor 1 gravitational thickener | ST_thick. | | Z4-A | 400 | 0.66 | 0.18 | IE1 | no | | 72.10 | 0.25 | 8700 | 1,737.59 | | 0.06 |
| motor 2 gravitational thickener | ST_thick. | | Z4-B | 400 | 0.66 | 0.18 | IE1 | no | | 72.10 | 0.25 | 8700 | 1,737.59 | | 0.06 |
| feed pump 1 | ST_thick. | | P1-A | 400 | 0.78 | 4.00 | IE1 | no | | 83.10 | 4.81 | 4380 | 16,866.43 | | 0.60 |
| polymer preperation unit 1 | ST_thick. | | T2-A | 400 | 0.60 | 0.75 | IE1 | no | | 72.10 | 1.04 | 4380 | 3,644.94 | | 0.13 |
| sludge compactor 1 | ST_thick. | | G2-A | 400 | 0.74 | 0.75 | IE1 | no | | 72.10 | 1.04 | 4380 | 3,644.94 | | 0.13 |
| transportation pump 1 | ST_thick. | | P2-A | 400 | 0.81 | 5.50 | EFF2 | no | | 85.70 | 6.42 | 4380 | 22,487.75 | | 0.80 |
| feed pump 2 | ST_thick. | | P1-B | 400 | 0.78 | 4.00 | IE1 | no | | 83.10 | 4.81 | 4380 | 16,866.43 | | 0.60 |
| polymer preperation unit 2 | ST_thick. | | T2-B | 400 | 0.60 | 0.75 | IE1 | no | | 72.10 | 1.04 | 4380 | 3,644.94 | | 0.13 |
| sludge compactor 2 | ST_thick. | | G2-B | 400 | 0.74 | 0.75 | IE1 | no | | 72.10 | 1.04 | 4380 | 3,644.94 | | 0.13 |
| transportation pump 2 | ST_thick. | | P2-B | 400 | 0.81 | 5.50 | EFF2 | no | | 85.70 | 6.42 | 4380 | 22,487.75 | | 0.80 |
| polymer dosage pump 1 | ST_thick. | | P3-A | 400 | 0.75 | 0.37 | IE1 | no | | 72.10 | 0.51 | 4380 | 1,798.17 | | 0.06 |
| polymer dosage pump 2 | ST_thick. | | P3-B | 400 | 0.75 | 0.37 | IE1 | no | | 72.10 | 0.51 | 4380 | 1,798.17 | | 0.06 |
| macerator 1 | ST_digest. | | RO1-A | 400 | 0.80 | 3.00 | IE1 | no | | 81.50 | 3.68 | 3650 | 10,748.47 | | 0.38 |
| feed pump 1 | ST_digest. | | P1-A | 400 | 0.78 | 4.00 | IE1 | no | | 83.10 | 4.81 | 3650 | 14,055.35 | | 0.50 |
| macerator 2 | ST_digest. | | RO1-B | 400 | 0.80 | 3.00 | IE1 | no | | 81.50 | 3.68 | 3650 | 10,748.47 | | 0.38 |
| feed pump 2 | ST_digest. | | P1-B | 400 | 0.78 | 4.00 | IE1 | no | | 83.10 | 4.81 | 3650 | 14,055.35 | | 0.50 |
| circulation pump 1 | ST_digest. | | P2-A | 400 | 0.78 | 6.50 | IE1 | no | | 84.70 | 7.67 | 3650 | 22,408.50 | | 0.80 |
| circulation pump 2 | ST_digest. | | P2-B | 400 | 0.78 | 6.50 | IE1 | no | | 84.70 | 7.67 | 3650 | 22,408.50 | | 0.80 |
| heat exchanger 1 | ST_digest. | | IO1-A | 400 | | 675.00 | IE1 | no | | 94.00 | 718.09 | 0 | 0.00 | | 0.00 |
| heat exchanger 2 | ST_digest. | | IO1-B | 400 | | 675.00 | IE1 | no | | 94.00 | 718.09 | 0 | 0.00 | | 0.00 |
| stirrer motor digester | ST_turno. | | M7 | 400 | 0.85 | 5.00 | IE1 | no | | 83.10 | 6.02 | 8700 | 41,877.26 | | 1.49 |
| stirrer motor pre-mixing tank | ST_other | | M6 | 400 | 0.86 | 2.75 | IE1 | no | | 79.70 | 3.45 | 8700 | 24,015.06 | | 0.85 |
| mixed sludge pump | ST_other | | P2-A | 400 | 0.86 | 2.25 | IE1 | no | | 79.70 | 2.82 | 1460 | 3,297.37 | | 0.12 |
| biofilter 2 | ST_other | | B2 | 400 | 0.82 | 1.50 | IE1 | no | | 77.20 | 1.94 | 8700 | 13,523.32 | | 0.48 |
| biofilter 4 | ST_other | | B4 | 400 | 0.80 | 0.75 | IE1 | no | | 72.10 | 1.04 | 8700 | 7,239.94 | | 0.26 |
| sum: | | | | | | **1,420.85** | | | | | **1,522.38** | | **284,737.19** | | **10.11** |
| **sludge dewatering** | | | | | | | | | | | | | refresh | | |
| decanter 1 | SE_FSE | 2006 | G2-A | 400 | 0.81 | 18.50 | EFF2 | no | | 90.00 | 20.56 | 3400 | 55,911.11 | | 1.99 |
| decanter 2 | SE_FSE | 2006 | G2-B | 400 | 0.81 | 18.50 | EFF2 | no | | 90.00 | 20.56 | 3400 | 55,911.11 | | 1.99 |
| polymer dosage station mixer | SE_Sonst | | W2 | 400 | 0.86 | 0.75 | IE1 | no | | 72.10 | 1.04 | 6570 | 5,467.41 | | 0.19 |
| polymer dosage station pump 1 | SE_Sonst | | P2-A | 400 | 0.86 | 0.37 | IE1 | no | | 72.10 | 0.51 | 365 | 149.85 | | 0.01 |
| polymer dosage station pump 2 | SE_Sonst | | P2-B | 400 | 0.86 | 0.37 | IE1 | no | | 72.10 | 0.51 | 365 | 149.85 | | 0.01 |
| polymer dosage station pump 3 | SE_Sonst | | P2-C | 400 | 0.86 | 0.37 | IE1 | no | | 72.10 | 0.51 | 365 | 149.85 | | 0.01 |
| screw pump 1 | SE_Sonst | | C1-A | 400 | 0.85 | 15.00 | IE2 | no | | 90.30 | 16.61 | 6570 | 87,308.97 | | 3.10 |
| dewatered sludge pump 1.1 | SE_Sonst | | P1-A | 400 | 0.86 | 1.10 | IE1 | no | | 75.00 | 1.47 | 6570 | 7,708.80 | | 0.27 |
| dewatered sludge pump 1.2 | SE_Sonst | | | 400 | 0.86 | 1.10 | IE1 | no | | 75.00 | 1.47 | 6570 | 7,708.80 | | 0.27 |
| screw pump 2 | SE_Sonst | | C1-B | 400 | 0.85 | 15.00 | IE2 | no | | 90.30 | 16.61 | 6570 | 87,308.97 | | 3.10 |
| dewatered sludge pump 2.1 | SE_Sonst | | P1-B | 400 | 0.86 | 1.10 | IE1 | no | | 75.00 | 1.47 | 6570 | 7,708.80 | | 0.27 |
| dewatered sludge pump 2.2 | SE_Sonst | | | 400 | 0.86 | 1.10 | IE1 | no | | 75.00 | 1.47 | 6570 | 7,708.80 | | 0.27 |
| sum: | | | | | | **73.26** | | | | | **82.78** | | **323,192.31** | | **11.48** |
| **other** | | | | | | | | | | | | | refresh | | |
| biogas blower motor | other | 2012 | | 400 | | 0.55 | IE1 | no | | 72.1 | 0.76 | 2190 | 1,336.48 | | 0.05 |
| sum: | | | | | | **0.55** | | | | | **0.76** | | **1,336.48** | | **0.05** |

**comparison of calculated electricity consumption and real electricity consumption:**

| | | |
|---|---|---|
| electricity production: | 125,008.32 | [kWh/a] |
| external electricity consumption according to energy supply company: | 3,370,929.45 | [kWh/a] |
| total electricity consumption: | 3,495,937.77 | [kWh/a] |
| electricity consumption according to consumption list: | 2,815,464.77 | [kWh/a] |

**APPENDIX 3.** Energy Analysis Tool: Data input, Kurenala WWTP

**2.) general operating data:**

| | | | |
|---|---|---|---|
| $Q_d$: | | [m³/d] | mean daily wastewater inflow |
| $B_{d,COD,aM}$: | | [kg/d] | daily COD-freight in inflow in anual average |
| $E_{ext}$: | | [kWh/a] | total purchased electricity (data from bill from EVU) |

**3.) feed pump stations:**

feed pump station existing? no

| | | | |
|---|---|---|---|
| - blow-in depth: | $h_d$ = | 3.65 | [m] |
| - friction losses: | $h_V$ = | | [m] |
| - efficiency air blower: | $\eta_{blower}$ = | | [-] |

c) primary settlement tank: **pr.se.tank**

number of scrapers: 1

d) pump stations:

pump station existing in mechanical cleaning stage? no — e.g. pump for primary sludge

d) other aggregates in mechanical cleaning stage **other**

number of aggregates 1 — e.g. sand washer, sand clasifier etc.

1 sand washer

**4.) mechanical cleaning stage:**

a) grid rack and screening plant: **screen**

number of aggregates: 5

2 screen
2 screen waste motor
1 pintalietepumppu

The number of aggregates contains in this case the number of coarse rack/fine screen or ratherwater strainer and also aggregates like rain good campactor etc.

b) grit chamber/grease trap:

number of scrapers: 0 **scraper**

number of aeration units: 1 **aeration**

- volume of grit chamber $V_{SF}$ = 50.00 [m³] Anzahl Becken: 2

- blow-in depth: $h_d$ = 3.65 [m]

## 5.) biological treatment stage:

cleaning process:
- activated sludge ☐
- trickling filter ☐
- membran bioreactor ☑

select the cleaning process, multiple selection is possible

**membrane bioreactor** — M_Bio

number of aggregates: 4 — 4 biorotor

**other pump stations:**

other pump station in the biological stage existing? no

**other aggregates in biological treatment stage:** — Bio_other

number of other aggregates 0

## 6.) secondary clarifier:

a)scraper:

number of scraper: 2 — SC_scra.

b) pumps for the excess sludge:

different boundary conditions? no — e.g. different kind of pump, different discharge head, Q

*pump station 1* — SC_PS1

kind of pump: other

number of pumps: 2 — 2 mammot pumps

amount of wastewater delive Q = [m³/a]

delivery head: $h_{deli}$ = [m]

- friction losses: $h_v$ = [m]
- hydraulic efficiency of pump: $\eta_{pump}$ = [-]
- efficiency of motor: $\eta_{motor}$ = [-]

c)other aggregates: — SC_other

number of other aggregates 4 — 2 mixers, 1 chemical´s pre-mixer, 1 polymer shaker

## 8.) sludge treatment:

a) surplus sludge thickening: ST_thick.

number of aggregates: 0

b)sludge digestion: ST_digest.

number of aggregates: 0 e.g. rabble rake, heating sludge pumps, circulation pump etc.

c) turnover of digestion tank: ST_turno.

number of aggregates: 0 e.g. screw pumps, external pumps

d) other aggregates: ST_other

number of other aggregates: 0

## 9.) sludge dewatering:

a) digested sludge dewatering: Sludge is not digested SE_FSE

number of aggregates: 6 included pumps for the dosage of polymers (if excisting)

kind of process: static postthickning

amount of digested sludge $Q_{FS}$ = [m³/a] SLUDGE is not digested

1 sludge pump for dewatered sludge,1 polymer pump (blue), 1 p

b) desintegration (ultrasound): SE_Desint

number of aggregates: 0

c) primary-sludge sieving: SE_PS-S

number of aggregates: 0

d) other aggregates: SE_Sonst

number of other aggregates: 0

## 10.) exhaust air cleaning

number of aggregates: 2 exh. air

air exchange $Q_L$ = 192 [1000m³/d]

total value of all plant components

## 11.) cogeneration plant

cogeneration plant existing? no

## 12.) heat consumption

a) total heat consumption:

$E_{th}$ = 90,000.00 [kWh/a] total heat consumption (heat production from cogeneration + consumption of external heat)

b) external heat consumption:

external heat consumption excisting? yes

energy carrie elect

$Q_{primary\ energy\ carrier}$: [-]

c) sludge treatment:

sludge digestion excisting? no

d) transmission losses of premises:

effective area: A = 738.00 [m²]

heat consumption: $E_{th,BG}$ = - [kWh/a]

## 13.) other

number of other aggregates: 5 1 septic tank screen, 1 screen waste presse **other**

2 sakokaivolietealtaan pumppua, 1 rejekti

**APPENDIX 4.** Energy Analysis Tool: Consumption list, Kurenala WWTP

## Energy analysis of clarification plants

consumption list

plant name: Kurenalan jätevedenpuhdistamo    year of data collection: 2016

| consumer | group | year of construction | system code | motor data: nominal voltage [V] | cosφ [-] | installed power [kW] | efficiency category [-] | frequency converter [-] | connected value: electricity actual state [A] | efficiency [%] | power calculated [kW] | duration time [h/a] | anual consumption [kWh/a] | fix value | proportion [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **feed pump stations** | | | | | | | | | | | | | | | |
| sum: | | | | | | 0.00 | | | | | 0.00 | | 0.00 | | 0.00 |
| **mechanical cleaning stage** | | | | | | | | | | | | | | | |
| Screen 1 | screen | | | 230 | 0.67 | 0.55 | IE1 | no | 3.0 | 72.1 | 0.40 | 2190 | 1,736.06 | | 0.00 |
| Screen 2 | screen | | | 230 | 0.67 | 0.55 | IE1 | no | 3.0 | 72.1 | 0.40 | 2190 | 1,736.06 | | 0.00 |
| Screen waste presser 1 | screen | | | 230 | 0.81 | 1.50 | IE1 | no | 5.9 | 77.2 | 1.16 | 790 | 1,504.02 | | 0.00 |
| Screen waste presser 2 | screen | | | 230 | 0.81 | 1.50 | IE1 | no | 5.9 | 77.2 | 1.16 | 790 | 1,504.02 | | 0.00 |
| Grit compressor (Aerzener GM 3S Delta Blower) | aeration | | | 400 | 0.87 | 4.00 | IE1 | no | 8.9 | 83.1 | 3.32 | 8760 | 46,993.09 | | 0.00 |
| Scraper (SEW R77 R37 DR63S4) | pr.se.tank | | | 230 | 0.63 | 0.12 | IE1 | no | 0.7 | 72.1 | 0.09 | 8760 | 1,495.00 | | 0.00 |
| Sand washer (BN80B-6) | other | | | 230 | | 0.55 | IE1 | no | | 72.1 | 0.40 | 730 | 231.59 | | 0.00 |
| sum: | | | | | | 8.77 | | | | | 6.92 | | 55,199.83 | | 0.00 |
| **biological treatment stage** | | | | | | | | | | | | | | | |
| Biorotor 1 | M_Bio | | | 230 | 0.75 | 2.20 | EFF2 | no | 9.0 | 81.0 | 1.78 | 8760 | 23,555.72 | | 0.00 |
| Biorotor 2 | M_Bio | | | 230 | 0.75 | 2.20 | EFF2 | no | 9.0 | 81.0 | 1.78 | 8760 | 23,555.72 | | 0.00 |
| Biorotor 3 | M_Bio | | | 230 | 0.77 | 2.20 | IE2 | no | 8.5 | 83.2 | 1.83 | 8760 | 22,867.20 | | 0.00 |
| Biorotor 4 | M_Bio | | | 230 | 0.77 | 2.20 | IE2 | no | 8.5 | 83.2 | 1.83 | 8760 | 22,867.20 | | 0.00 |
| sum: | | | | | | 8.80 | | | | | 7.22 | 8760 | 92,845.83 | | 0.00 |
| **secondary clarifier** | | | | | | | | | | | | | | | |
| Scraper 1 | SC_scra. | | | 230 | 0.69 | 0.12 | IE1 | no | 0.7 | 72.1 | 0.09 | 8760 | 1,637.38 | | 0.00 |
| Scraper 2 | SC_scra. | | | 230 | 0.69 | 0.12 | IE1 | no | 0.7 | 72.1 | 0.09 | 8760 | 1,637.38 | | 0.00 |
| Sarlin/Grundfos SV 014 BL6 | SC_PS1 | | | 400 | 0.87 | 1.65 | IE1 | no | 4.3 | 67.2 | 1.11 | 7300 | 18,920.44 | | 0.00 |
| Sarlin/Grundfos SV 014 BL6 | SC_PS1 | | | 400 | 0.87 | 1.65 | IE1 | no | 4.3 | 67.3 | 1.11 | 6800 | 17,624.52 | | 0.00 |
| Polymer mixer 1 | SC_other | | | 230 | 0.78 | 0.18 | IE1 | no | 1.0 | 72.1 | 0.13 | 8760 | 2,613.11 | | 0.00 |
| Polymer mixer 2 | SC_other | | | 230 | 0.68 | 0.37 | IE1 | no | 2.3 | 72.1 | 0.27 | 8760 | 5,339.30 | | 0.00 |
| Chemical pre-mixer | SC_other | | | 230 | 0.73 | 0.75 | IE1 | no | 3.7 | 72.1 | 0.54 | 8760 | 9,298.40 | | 0.00 |
| Polymer shaker | SC_other | | | 230 | 0.68 | 0.37 | IE1 | no | 2.3 | 72.1 | 0.27 | 0 | 0.00 | | 0.00 |
| sum: | | | | | | 5.21 | | | | | 3.60 | | 57,070.54 | | 0.00 |
| **Posttreatment** | | | | | | | | | | | | | | | |
| sum: | | | | | | 0.00 | | | | | 0.00 | | 0.00 | | 0.00 |
| **sludge treatment** | | | | | | | | | | | | | | | |
| sum: | | | | | | 0.00 | | | | | 0.00 | | 0.00 | | 0.00 |
| **sludge dewatering** | | | | | | | | | | | | | | | |
| Sludge pump for dewatered sludge | SE_FSE | | | 400 | 0.79 | 2.20 | IE2 | no | 4.7 | 79.70 | 1.75 | 1500 | 3,817.61 | | 0.00 |
| Polymer pump | SE_FSE | | | 400 | 0.75 | 0.75 | IE2 | no | 1.8 | 68.66 | 0.52 | 1500 | 1,371.78 | | 0.00 |
| Polymerdosage pump | SE_FSE | | | 400 | 0.64 | 0.18 | IE1 | no | 0.7 | 89.44 | 0.16 | 350 | 108.63 | | 0.00 |
| Polymer mixer pump | SE_FSE | | | 230 | 0.73 | 0.75 | IE1 | no | 3.7 | 83.40 | 0.63 | 350 | 371.51 | | 0.00 |
| Sludge dewatering motor (mixer) | SE_FSE | | | 230 | 0.77 | 0.25 | IE1 | no | 1.3 | 87.20 | 0.22 | 8760 | 3,546.97 | | 0.00 |
| Dryer motor | SE_FSE | | | 400 | 0.83 | 2.20 | IE1 | no | 5.1 | 62.59 | 1.38 | 1700 | 4,985.60 | | 0.00 |
| | SE_PS-S | | | | | | IE1 | no | | 0.00 | 0.00 | | 0.00 | | 0.00 |
| sum: | | | | | | 6.33 | | | | | 4.65 | | 14,202.12 | | 0.00 |
| **exhaust air cleaning** | | | | | | | | | | | | | | | |
| Income air blower motor (DC) | exh. air | | | 400 | | 4.00 | IE1 | no | 8.6 | 86.00 | 3.44 | 8760 | 35,040.00 | | 0.00 |
| exhaust air blower motor (DC) | exh. air | | | 400 | | 4.00 | IE1 | no | 8.6 | 86.00 | 3.44 | 8760 | 35,040.00 | | 0.00 |
| transfer air blowe (DC) | | | | 400 | | 0.37 | | | 1.2 | 129.73 | 0.48 | 8760 | 3,241.20 | | |
| transfer air blowe (DC) | exh. air | | | 400 | | 0.52 | IE1 | no | 1.7 | 126.92 | 0.66 | 8760 | 4,555.20 | | 0.00 |
| sum: | | | | | | 8.89 | | | | | 8.02 | | 77,876.40 | | 0.00 |
| **other** | | | | | | | | | | | | | | | |
| Septic tank screen | | | | 230 | 0.67 | 0.55 | IE1 | no | 3.0 | 72.1 | 0.40 | 70 | 38.50 | | |
| Septic tank screen waste presser | | | | 230 | 0.81 | 1.50 | IE1 | no | 5.9 | 62.4 | 0.94 | 30 | 45.00 | | |
| Septic tank sludge pump 1 (Sarlin/Grundfos SV 014 B1) | | | | 400 | 0.87 | 1.65 | IE1 | no | 4.3 | 67.3 | 1.11 | 80 | 132.00 | | |
| Septic tank sludge pump 2 (Sarlin/Grundfos SV 014 B1) | | | | 400 | 0.87 | 1.65 | IE1 | no | 4.3 | 67.3 | 1.11 | 80 | 132.00 | | |
| Reject water (sarlin sv 014 b1vd501p) | | | | 400 | 0.87 | 1.65 | IE1 | no | 4.3 | 67.3 | 1.11 | 4500 | 7,425.00 | | |
| Reject water 2 (sarlin sv 014 b1vd501p) | | | | 400 | 0.87 | 1.65 | IE2 | | 4.3 | 67.3 | 1.11 | 4500 | 7,425.00 | | |
| sum: | | | | | | 0.00 | | | | | 5.78 | | 15,197.50 | | 0.00 |
| **premises** | | | | | | | | | | | | | | | |
| electricity consumption premises | | | | | | | | | | | | | | | 0.00 |
| workshops, laboratories, etc. | | | | | | | | | | | | | | | 0.00 |
| sum: | | | | | | | | | | | | | 0.00 | | 0.00 |

**comparison of calculated electricity consumption/real electricity consumption:**

| | | |
|---|---|---|
| electricity production: | 0,00 | [kWh/a] |
| external electricity consumption according to energy supply company: | 0,00 | [kWh/a] |
| total electricity consumption: | #ARVO! | [kWh/a] |
| electricity consumption according to consumption list: | 312,392.22 | [kWh/a] |

**Appendix 5**, Electricity consumption per cubic meter for wastewater treated calculations

| | | | | |
|---|---|---|---|---|
| Zdroje | | | | |
| | | | kWh/a | kWh/m3 |
| **feed pump stations** | | | 269,584.25 | 0.052 |
| **mechanical cleaning stage** | | | 106,013.46 | 0.021 |
| **biological treatment stage** | | | 1,820,097.38 | 0.35 |
| **secondary clarifier** | | | 10,503.70 | 0.002 |
| **Posttreatment** | | | 0.00 | 0.000 |
| **wastewater treatment total** | | | 0.00 | 0.000 |
| **sludge treatment** | | | 284,737.19 | 0.055 |
| **sludge dewatering** | | | 323,192.31 | 0.063 |
| **exhaust air** | | | 0.00 | 0.000 |
| Other | | | 1,336.48 | 0.000 |
| | | | | |
| Q total (m3) | 5,146,161.00 | | | |
| e-cons.total (kWh | 2,815,464.77 | | | |
| | | | m3/kWh | |
| | 2,815,464.77 | | 0.55 | |
| Sludge treatment total | | 0.118 | | |

| | | | | |
|---|---|---|---|---|
| Kurenala | | | | |
| | | | kWh/a | kWh/m3 |
| **feed pump stations** | | | 0.00 | 0.000 |
| **mechanical cleaning stage** | | | 55,119.83 | 0.011 |
| **biological treatment stage** | | | 92,845.83 | 0.02 |
| **secondary clarifier** | | | 57,070.54 | 0.011 |
| **Posttreatment** | | | 0.00 | 0.000 |
| **wastewater treatment total** | | | 0.00 | 0.000 |
| **sludge treatment** | | | 0.00 | 0.000 |
| **sludge dewatering** | | | 14,202.12 | 0.003 |
| **exhaust air** | | | 77,876.40 | 0.015 |
| **Other** | | | 15,197.50 | 0.003 |
| | | | | |
| Q total (m3) | 426,466.00 | | | |
| e-cons.total (kWh) | 312,312.22 | | | |
| | | | m3/kWh | |
| | 312,312.22 | | 0.73 | |
| Sludge treatment total | | 0.003 | | |