Lappeenranta-Lahti University of Technology LUT

School of Engineering Sciences

LUT School of Engineering Sciences

Master´s programme in Chemical Engineering and Wastewater treatment

Master's Thesis

2021

Abdelhalim Samaka

EFFECTS OF VARIABLE FEEDS IN WASTEWATER PLANTS BY MEANS OF PROCESS SIMULATION

Examiners: Professor Tuomas Koiranen, Professor Satu-Pia Reinikainen

Supervisor: D.Sc. Esko Lähdenperä

ABSTRACT

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76 pages, 36 figures, 27 tables.

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Keywords: wastewater treatment plant, flood, dry weather, simulation, chemical treatment, biological treatment

Literature review of wastewater plants

Process simulation of wastewater processes

- First simulations are roughly models of unit operations.
- The models can be furthermore detailed if needed.
- Several different scenarios are simulated.
- Results are analysed based on the plant operation characteristics.

Outline

In this study different feed conditions are simulated by solving steady-state mass and energy balance equations using SteadyState process simulation tool. The minimum and maximum values of feed stream parameters are used in simulations which were designed to correspond extreme weather conditions. The simulation results are used for describing process sensitivity and thus the process behaviour is better understood at limiting conditions. The combined effects of feed stream parameters can also be studied efficiently to the parameters describing process operation. Also, the

effect to each process units can be clarified which may give valuable information for corrective and preventing actions in this kind of extreme weather conditions.

The main findings are the wastewater process unit level results. A large group of simulations are produced in order to find the effluent concentration of contaminant as Nitrogen or Ammonia.

Wastewater plant units, such as pre-clarification, denitrification and chemical additions have operational design specifications like for example designed tank volumes or designed feed concentrations which may not be exceeded. Thus, it is possible to control circulation streams, chemical amounts and construct additional buffer tanks based on this kind of process simulation results analysis.

ACKNOWLEDGEMENTS

This Master's thesis was carried at the Lappeenranta University of Technology. I want to express my gratitude to my supervisors, Esko Lähdenperä, Tuomas Koiranen, and Satu-Pia Reinikainen. Also, I want to express my thanks to my family members for their supports.

Abdelhalim Samaka,

2020, Lappeenranta, Finland.

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LIST OF ABREVIATIONS

BOD	biochemical oxygen demand
COD	influent soluble substrate concentration
CH4	methane
CO	carbon monoxide
CO2	carbon dioxide
qm	mass flow [kg/s]
H2	hydrogen
H2O	water
M	molar mass [g/mol]
m	mass [kg]
N2	nitrogen
WWTP	wastewater treatment plant [-]
BOD	Biological oxygen demand
COD	Chemical oxygen demand
NaCl	Sodium chloride
NH3	Ammonia
NH4	Ammonium
NOM	Natural organic matter
N2	Nitrogen
O2	Oxygen
CSO	combined sewer overflow

1. Introduction
1.1. Background

The wastewater is the influent water, which flows from residential or in other words it is the wastewater of domestic origin. Wastewater can be also originally of commercial, industrial, agricultural or other. This water is contaminated and needs to be threated to meet regulations and standards to be discharged to natural water bodies.

Extreme weather conditions may cause heavy rain seasons or long dry seasons which set new challenges to the wastewater plant operation. In Finland seasonal variation is characterized by cool, dark winters and light summers. Some of these challenges can be prepared for example by simulating the wastewater process at different inlet conditions. The feed stream flow rates may be exceeded from the designed maximum values, and the compositions may vary a lot in extreme climate conditions. In the extreme, the wastewater inlet streams may be bypassed through the treatment plant. The goal of this study is to simplify trouble shooting work and the effect analysis when this kind of situations are considered in advance.

Before the wastewater can be discharged to recipient nature or prepared for reuse, it goes through a system of collecting, canalization till the WWTP. After that is goes through different stage of cleaning process: primary clarification, chemicalization, biological treatment in aeration basin, and secondary clarification

The modelling of activated sludge plants is one of the most importing part for the Wastewater treatment simulation and building of the wastewater treatment plants process plant. The biological treatment step is a crucial step in the wastewater treatment plant because it defines the purification efficiency, and it is of low costs. The activated sludge process modelling needs a large data and several parameters to be analysed to make the process and the plant working efficiently. Before starting the modelling, the simulations, must be done in order to make an insight about the feasibility of the project.

Modelling is an inherent part of the design of a wastewater treatment system, regardless of the approach used (Henze, et al., 1987). For the processing of the organic matter in the effluent, activated sludge is used because of its low price comparing to the use of chemical treatment to neutralize pollutants.

The Activated sludge model is the most important part of the WWTP simulation and design. In this units, takes part the COD, BOD, Nitrogen, Ammonium, and Phosphorus elimination or neutralisation. all these contaminants are irradiated by biologically treatment.

The effect of extreme weather on the function of wastewater treatment plants is very high. With the last decades temperature increasing and the sea or ocean level increasing, are influencing the re-design of units and the sites of the wastewater treatment plants in different part of the world.

Different approaches had been made by different methods. Methods used vary from mathematical models of activated sludge modelling or using MATLAB software for mathematical modelling or some specific WWTP software programmes, as: Water Quality Analysis Simulation Program (WASP), GPS-X software, West simulation, BioWin, and Steady state.

1.2. Aims and objectives

A modelling and simulation of WWTP is very important to forecast the process of WWTP with different feeds and flows. Thus, a mathematical simulation or a software is the ideal in this case. Small pilot-plant can be also used, but because of the time consuming and high costs they are difficult to implant it.

The objective of this Master´ s thesis was to study the effect of simulation of the work of WWTP, also the study was to give certain results and recommendation about the operation of the WWTP, the process design, perform the operation of the WWTP processes. Simulation of WWTP by a software (steady state), is needed in order to simulate certain theory about the process of WWTP with less investment and time. This model will help to optimize the process of the Nitrogen removal. The virtual laboratory is the optimum and low-cost method to assume the work of WWTP.

The Turku´s WWTP was used as a model for simulation. The BOD, COD, total nitrogen and TSS, data was used to perform modelling and simulation. Different data entrance will be given for the simulation, apart temperature and phosphorus data. It will be suggested and simulated two different stages of the WWTP work. First, it will be simulated the work of WWTP with different flow rate level, going from minimum to a maximum flow, in the yearly peaks. In the first simulation was take the lowest flowrate in the second simulation, it will be simulated a state when the flow rate reached the yearly maximum.

The first simulation was done with low flow rate, 125, 250 and 500 L/s. The later simulations were done with a flow rate of 600, 700, 800, 900 and 1000 L/s. In those situations, an overflow was done directly to a sand filtration. The data was collected from the Turku´s WWTP, which is given in the yearly report, at the company web site.

It was concluded that in case of extreme weather, the effluent concentration of Nitrogen or ammonia or TSS are in times higher in by-pass than in the normal situation of the work of the Turku wastewater treatment plant.

In conclusion, will be discussed the simulations itself, the calibration model will be elaborated, and furthermore from the calibration, a model of the WWTP simulation will be developed.

In the literature part different software for simulation and modelling will be discussed. The wastewater treatment process and units also will be discussed, and it will be given factors influencing the WWTP simulation and d working. A pilot plant for the simulation will be presented and discussed. It will be also given the concentrations and flow rates for the simulations.

The target of this thesis is to analyses and simulate WWTP with different effluent flowrates and concentrations. The Turku´s region wastewater treatment plant will be studied. Turku is as city situated in the South-western part of Finland.

2. Literature part

In the literature part different software for simulation and modelling will be discussed. The wastewater treatment process and units also will be discussed, and it will be given factors influencing the WWTP simulation and d working. A pilot plant for the simulation will be presented and discussed. It will be also given the concentrations and flow rates for the simulations.

The target of this thesis is to analyses and simulate WWTP with different effluent flowrates and concentrations. The Turku´s region wastewater treatment plant will be studied. Turku is as city situated in the South-western part of Finland.

2.1. Introduction to wastewater treatment in Finland

The Finnish wwtp history is very long, the firsts sewage in the Helsinki region is up to 1883, and the first sewage system was built in 1875, at this time, Helsinki's inhabitant was about 30000 (Juuti, 2010) .Solid sludge was collected from houses and transported by charettes then by train to the dump place as shown at Figure1. There was more pressure to build a normalized sewage system and wastewater treatment plant as contamination and health concerns grows, the first contamination was in the Töölö bay in the Helsinki centre. The first activated sludge model was built in the 1930´s,the Alppila wwtp used gravel filters, as show in Figure 2, building site of the Alppila wwtp is shown at Figure 3. At the 1970´s Helsinki has already 11 WWTP facilities (Juuti, 2010). in the city of Lahti (Finland) Kaarlo Tavast installs the first septic tanks. in the early

1907-1908 years, Dunbar William Philips developed the first Finland made septic tanks, the one installed in Lahti were with a volume of 150 m3, in Helsinki the were of a 100m3 volume (Juuti, 2010).

Figure1: Solid sludge collected from houses from Helsinki and transported by *charette* then by train to the Malmi dump place. Picture from 1913, HKM as cited in (Juuti, 2010).

Figure 2: Alppila wwtp Gravel filter (picture Roos 1941, as cited in (Juuti, 2010)

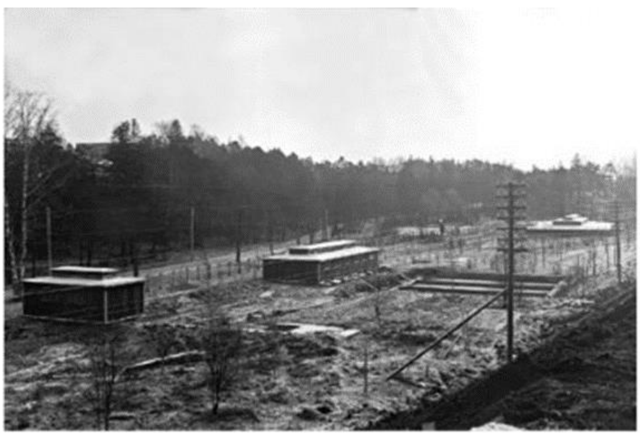


Figure 3: First Helsinki WWTP constructed in Alppila 1910, picture Roos as cited in (Juuti, 2010)

An example of wastewater treatment in Finland, is the Viikinmäki wastewater treatment plant in the Helsinki region. It is totally built in the underground as shown in Figure 4, and its cross section is represented at Figure 5 . The wastewater arrives at the plant via an extensive tunnel network. Also, the treated wastewater is discharged into the sea via a rock tunnel, which capacities is 1.2 million m^3 (Vähäaho, 2014).

Figure 4: An aera view of the Viikinmäki WWTP (city of Helsinki real estate department as cited in (Vähäaho, 2014)

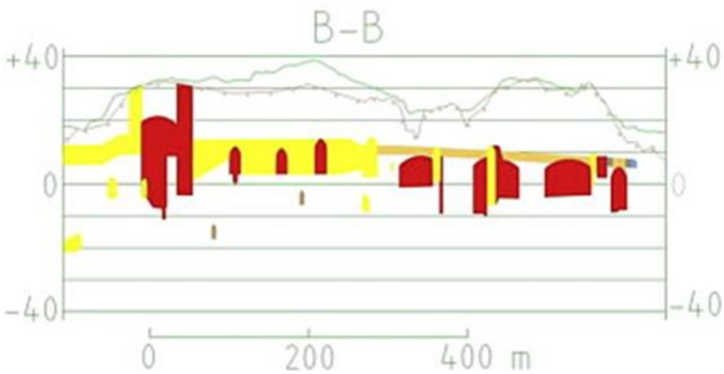


Figure 5: The Viikinmäki WWTP (Vähäaho, 2014)

2.1.1. water legislation in Finland

According to the Flood risk management act (N⁰. 620/2010), the flood risks must be reduced, prevention and mitigation the adverse consequences caused by flood must be taken, also the of preparedness for flood must be promoted. The Ministry of Agriculture and Forestry is the principal of the purpose of this act (Ministry of Agriculture and Forestry, 2010).

For the planning of stormwater and meltwater flood risk management, there is also some Acts preventing and promoting the risk of floods, as the section 19 of the Flood Risk Management Act (N⁰. 620/2010), which claims that the municipality undertakes s preliminary assessment of flood risks caused by stormwater and meltwater and must prepare for flood hazard maps (Ministry of Agriculture and Forestry, 2010).

Another Act regularizes the development and organization of water services. In chapter 2 section 5 of the water services act (119/2001) (amendments up to 979/2015 included) (Ministry of Agriculture and forestry, 2015), claims that a municipality shall develop water services and sewerage in its territory in accordance with the development of communities to meet the objectives of this act. In the chapter 3 section 10; connecting a property to the network of a water utility (681/2014) (Ministry of Agriculture and forestry, 2015), it explains the connection to the network of water utility and management of water services.

In chapter 3a, of the Organization and management of sewerage for runoff water (681/2014), section 17a, it explains the organization of sewage for runoff water. One exception of the connecting of a building to the runoff water to the sewer system is a building runoff water quantity or quality interferes with the operation of water quality (Ministry of Agriculture and forestry, 2015).

2.1.2. Swedish legislation

Sweden also had developed a requirement, acts and recommendations for the road runoff and road drainage, which are shown in Table 1 with the number of act or requirements and the explanation of it.

Table 1: STA publications of Swedish act and recommendation of handling road runoff and road drainage water (TRAFIKVERKET, 2018).

Requirements	**2014:0045**	**Drainage – technical requirements for drainage**
Recommendation	**2011:112**	**Stormwater – advice and recommendations for environmental action plan**
	2014:0046	**Drainage**
	2014:0051	**Drainage – Design and dimensioning**
Handbook	**2013:135**	**Surface and ground water protection**
	2015:147	**Open stormwater treatment plants – Inspection and Maintenance**
Publication stormwater treatment plants	**2003:188**	**Stormwater ponds – Investigation of function and efficiency**
	2006:115	**Stormwater ponds – Sampling, sedimentation and hydraulic**
	2008:30	**Maintenance of open**

2.1.3. Norwegian legislation

For Norway, before 1970s the focus was on managing water quantities and not stormwater or runoffs, but for the last decades Norwegian NPRA, had published some recommendation on roads runoffs management when building roads, (TRAFIKVERKET, 2018). One recommendation is seen in the Figure 6 which represents the design of infiltration for treatment of roads runoffs.

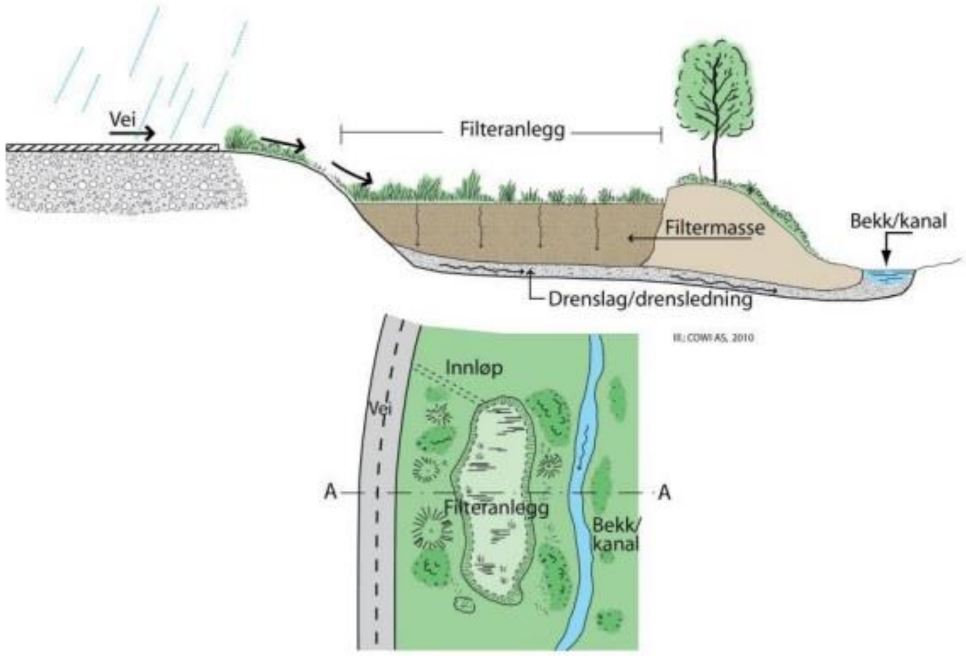


Figure 6: Design of infiltration filter for treatment of road runoff. NPRA agency (Norway) Håndbok N200 as cited in (TRAFIKVERKET, 2018)

2.1.4. German legislation

For Germany´s legislation, the DWA (German association for water, wastewater and waste) had published acts on the treatment suspended of solids. The recommendations are presented in the Table 2.

Table 2: Treatment requirement according to annual suspended solids < 63 µm (AFS63, as cited at (TRAFIKVERKET, 2018)

AFS63 transport (kg/ha per year)	Pollutant load	Action
< 280	Insignificant	Treatment generally not required
280 - 530	Moderate	Treatment required in most cases
> 530	High	Treatment required for all cases

The first treatment facilities in Germany were built in the early 1960s to protect groundwater from flood, the number of runoff facilities is now estimated to be more than 1000. The Figure 7 shows an example of the facilities which are sedimentation/retention basins followed by soil filter infiltration facilities (TRAFIKVERKET, 2018)

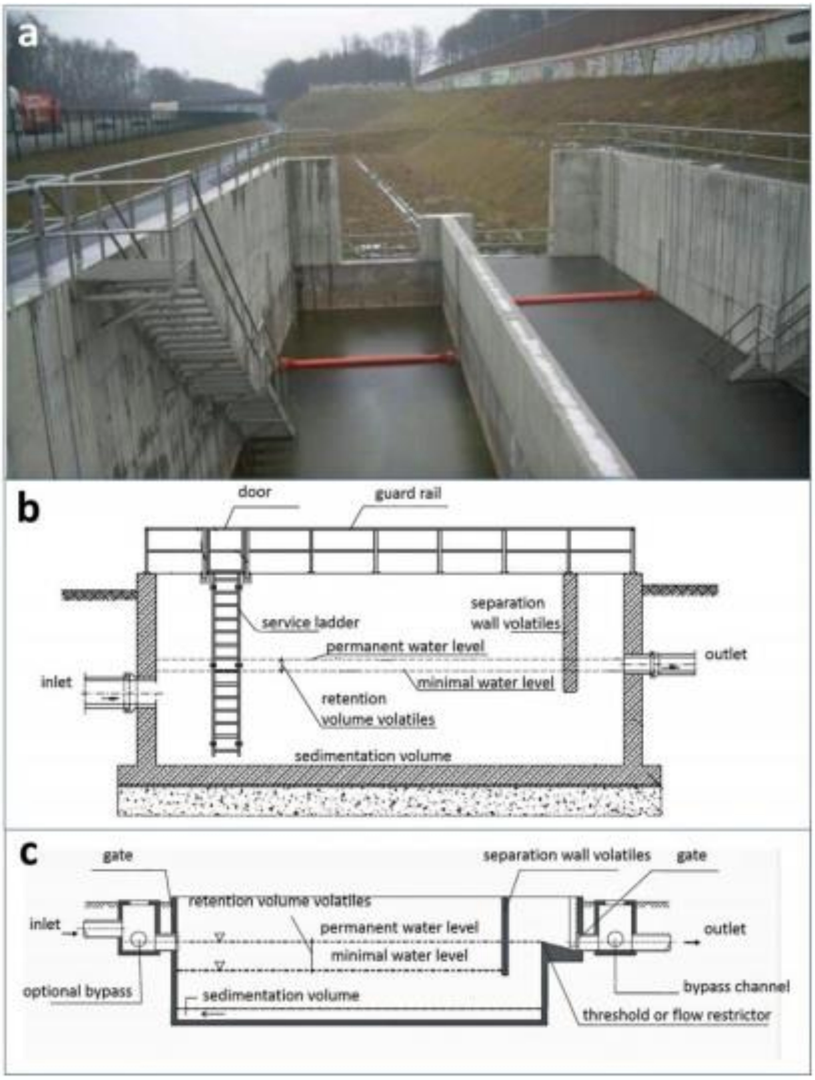


Figure 7: Centralized treatment facilities in Germany for road stormwater and runoff, Birgit Kocher, BASt (a), DEGER (b) and FGSV (c) as cited at (TRAFIKVERKET, 2018).

2.2. WWTP process.

All WWTP are designed to use these stages of treatment, which are:

- Preliminary
- Primary
- Advanced primary
- Secondary
- Secondary with nutrient removal
- Tertiary
- Advanced treatment

The Unit operations and process is used to remove constituents as:

- Suspended solids
- Biodegradable organics
- Nutrients
- Pathogens
- Colloidal and dissolved solid
- Volatile organic compounds
- Odour

The first step in the WWTP unity, the preliminary is the screening. It this step, coarse material is removed. Solid waste, as paper, plastic, kid pampers, women pamper, and metals are removed. A second step of fine screening can be also used to remove fine materials. Those wastes if not removed can make damage to the pumps or to the treatment plant parts. According to (Metcalf and Eddy, 2003), different unit of screening can be used, as coarse screens (bars racks), hand-cleaned coarse screens, which are use used in small wastewater pump stations, and mechanically bars screens. At the step of grit removal which is usually comes after the bar screen, small solids as gravel or sand are removed. Grit chambers protect moving mechanical equipment from abrasion and reduce formation of heavy deposit in pipelines (Metcalf and Eddy, 2003). Mixing and flocculation is also an important step in the WWTP units, it allows to mix all the compounds together and blend all the liquids together.

Flocculation is completed in a separate basin or unit. Flocculation is done by mechanically or by air agitation to increase removal of suspended solids and BOD (Metcalf and Eddy, 2003). The aeration tank or diffusion air flotation tank or DAF tank is a tank where the oxygen is added by dissolving it into water this is made by surface agitating which allows the oxygen to enter and to mix with water. Other methods used are such using pumps to infilter to the water tank., or the use of propellers or turbines. The amount of oxygen is calculated of the mass of aerobic bacteria existing in the aeration tank. the role of aerobic bacteria is capital for the removal of nutrients such phosphorus or nitrogen present in the wastewater, thus the biological treatment is crucial for the whole stage of the WWTP process.

The removal of suspended and colloidal material is widely used in WWTP, this can be accomplished by sedimentation. Inclined plate and tube settling or countercurent settling or hindered zone settling are used (Metcalf and Eddy, 2003). The tertiary treatment step is done by using of chemicals as Ozone, chlorination and hydrogen peroxide.

The Figure 8, represents the typical wastewater treatment plant process. The influent wastewater from residential goes through a primary settling tank. After that it goes through gravity thickener. The diffusion air flotation units allow to collect of the flocculants on the top of the surface, then with a coarse it is collected and goes to the sludge dewatering unit. After DAF unit it goes to a sludge digestion. The wastewater from the DAF unit is transported to activated sludge process units. The ASM process units are constituted from an activation tank and a clarifier unit.

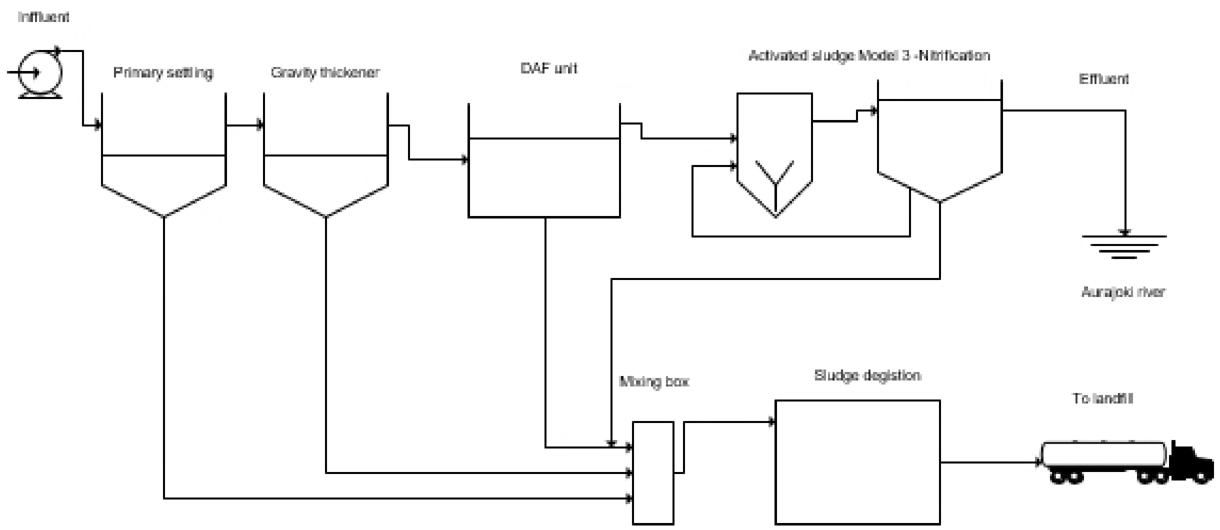


Figure 8: Wastewater treatment unit process.

2.3. Weather effects on WWTP

Due to the elements, flood, hurricanes, quick raining, quick ice melting, the WWTP plant in different part of the world faces injuries due to growing water level at the WWTP sites. Last USA´s hurricanes had shown banks overflow, flashy flooding. The Figure 9 shows an example of the flooding on a WWTP in the USA after a Hurricane. The flood can affect the drinkable water for the inhabitant, due to the use of water from the WWTP facilities.

Figure 9: Flooding IA North wastewater, Iowa city WWTP after Hurricane in 2008, USA (Iowa Homeland Security and Emergency Management, 2008).

2.3.1 Effect of daylight on bacteria growth.

Different studies have different result and conclusion about the effect of daylight on different bacteria growth or inhibition.

First of studies was conducted on different lakes in Sweden, (Lindell, 1996), In which the Autor assumes that the DOC (dissolved organic carbon) doe s does not change if it was conducted in light or dark samples after exposure at any depth or lake. Also, the author, says that bacteria may be influenced by inhibition or stimulation by solar radiation. He suggested that the inhibition may occurs when inhibitor substances like radical are produced due to UV light like superoxide and hydrogen peroxide. Also, bacteria can benefit from UV light with photolysis and conversion of DOM (dissolved organic matter) to bacterial substrates. the loss of bacteria in light samples varied from 23 % in humic lakes, to 85% in clear lakes compared to samples in dark controls (Lindell, 1996). in one sample of Straken lake, the bacteria cultures were identical independently of light or dark or depth. the only factor was the relationship between the bacteria growth and DOC, as shown in the Figure **10**.

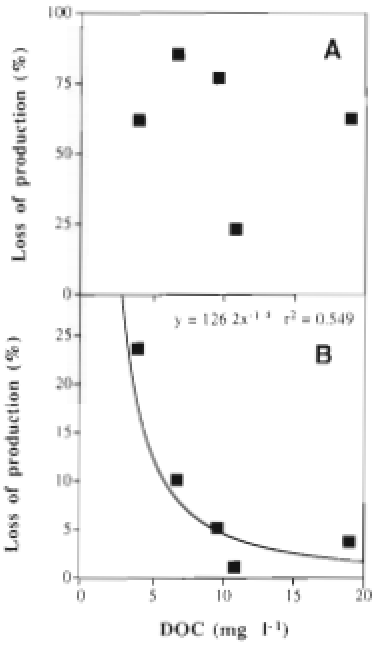


Figure 10: Loss of bacterial production in relation to DOC content (A) at surface and (B) depth integrated. (Lindell, 1996)

The second study was conducted on faecal coliforms and (FC) and faecal streptococci (FS) trying to found the effect of sunlight on their growth. (Fujioka, 1982) for the (FC) and (FS) the effect of sun light was catastrophic, the bacteria was reduced by 99% after an exposure to sunlight of 20min. The Figure **11**, shows the sunlight effect on bacteria growth.

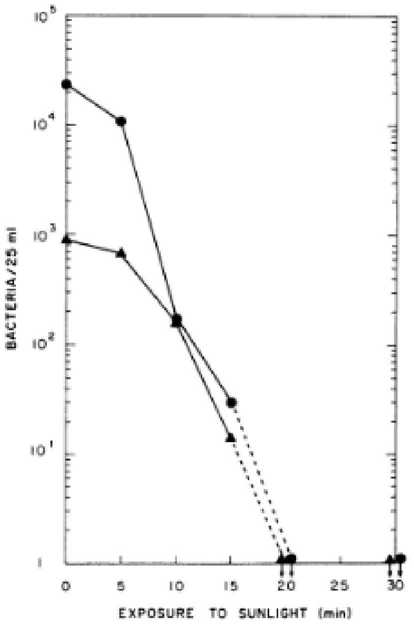


Figure 11: Effect of sunlight on survival of FC and FS. (Fujioka, 1982)

The third study (Coohill, 2003), conducted on effect of wavelength on E. Coli. Assumes with the experiment conducted on the effect of wave light on bacteria that the activation or inhibition of bacteria by sunlight is a more complex interplay between different factors. Factors can be named as, biological parameters, photoproducts, temperature and solar wave light now of the experiences. The solar light can damage the DNA of bacteria, but it is depending on the solar wave light.

(Coohill, 2003) admits that there is correlation between cell inhibition and the solar irradiation at different day time. The bacterial activity growth deceases accidently at 12:00 which characterized the highest activity of sun radiation. The bacterial activity and growth as shown in Figure 12, increases after 12:00 which corresponds to decreasing of sun radiation,

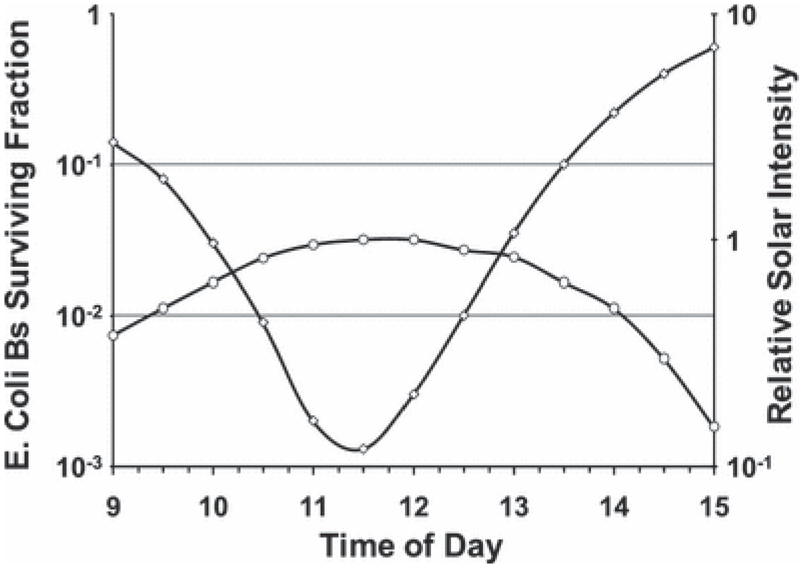


Figure 12: E. Coli growth comparing to solar radiation intensity (Coohill, 2003)

From the Figure 13 , we can see different bacteria used in the WWTP. Each bacterium has own living temperature diapason. The Psychrophiles temperature is from -5 to 20 ^{0}C, with a peak at +10 ^{0}C. The Mesophiles temperature range starts from +15 to +45 ^{0}C. The thermophiles temperature range is between +45 to 80 ^{0}C. The highest temperature range is of the Hyperthermophiles which is from +65 to +110 ^{0}C (Eckenfelder, 1980).

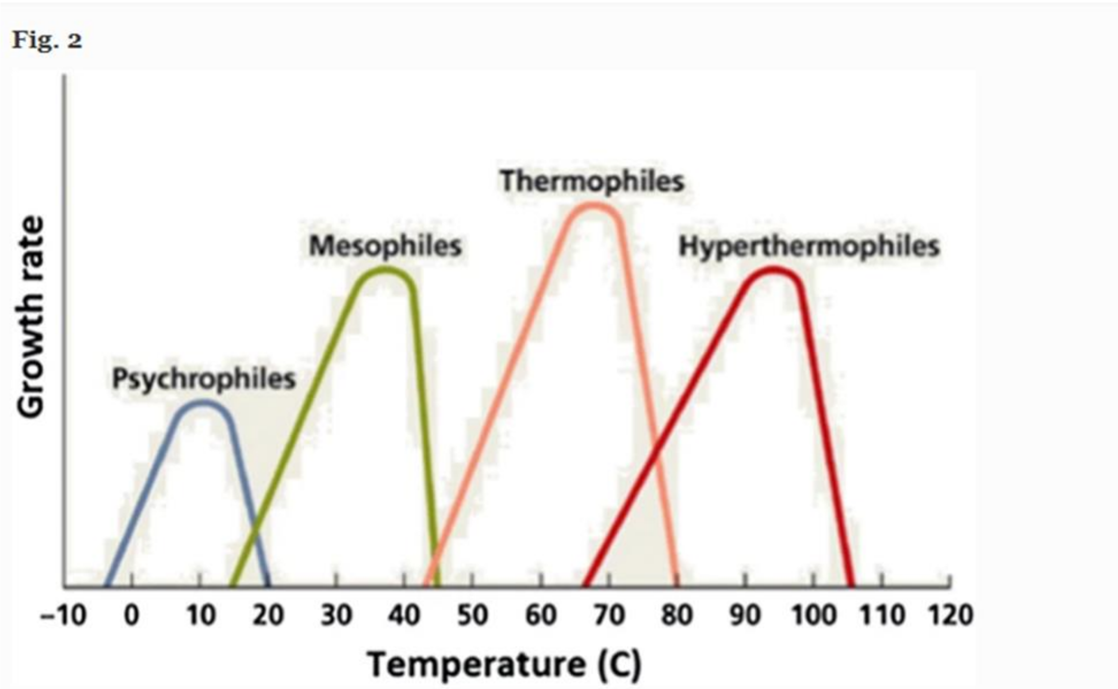


Figure 13 : Bacteria temperature diapason (Eckenfelder, 1980)

(Metcalf and Eddy, 2003), confirms that the temperature affects the biological treatment process especially the bacteria growth. according to Van´t Hoof-Arrhenius equation **1** shown below, the bacteria growth is exponentially depending on temperature.

$$K_T = K_{20}\theta^{(T-20)} \quad 2$$

K_T : **coeffecient of reaction rate** T, ⁰C

K_{20} : ***coefficient of equation rate at 20 ⁰C***

2.3.2 Daylight prolongation and rain falls

The Figure **14**, illustrates the total daylight in the Rovaniemi region. As seen from the graph the winter daylight time is very short. From the begging of December till the end of January, the daylight does not exceed four (4) hours. At the summertime, the daylight reaches the maximum of 24 hours between 15een of June till 1st of July. Between 15 of May and 1st of August the daylight prolongation is more 20 hours.

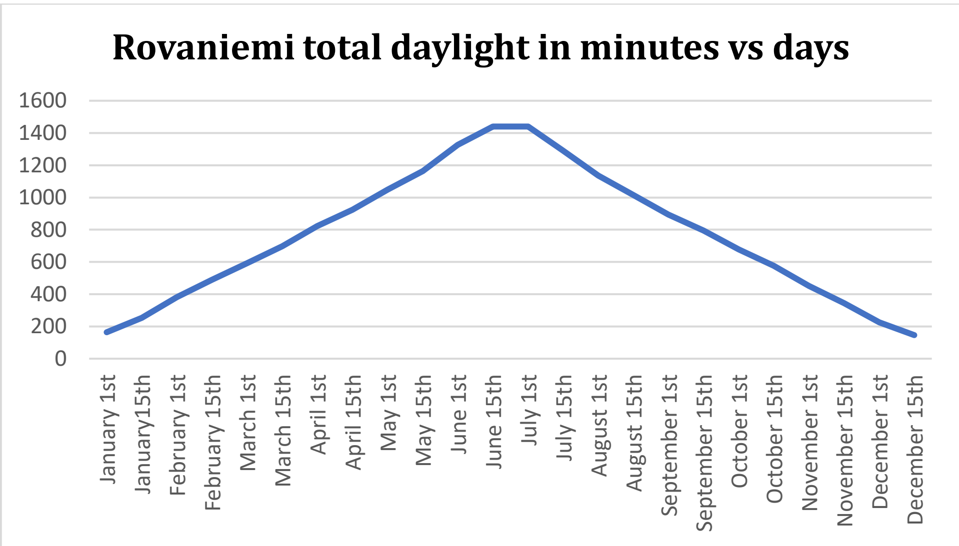


Figure 14: Rovaniemi city total daylight in minutes vs days (laplandsafaris.com, 2020)

The Table 3 represents the temperature averages and the rain average of the Rovaniemi region. The temperature average does not exceed 15 ⁰C and does not go below -14 ⁰C. Thus, there is a spread of differences in the temperature averages, starting from may the temperature is above 0 ⁰C, till the end of September, with peaks in July with an average of 14⁰C. In wintertime there is peaks in January and February of about – 14 ⁰C.

For the rains monthly averages there is big differences in different months. The minimum can be seen in the wintertime with an average of 30 mm in February, the maximums is meet in summertime with peaks in July and august, about 78 mm.

Table 3: Rainfall and temperature averages of Rovaniemi region (Kersalo, 2009)

Months	Temperature average. degree C	Rains average per months (mm)
1	-13.2	36
2	-12.1	29
3	-7.1	31
4	-2	33
5	5	44
6	11.6	68
7	14.3	78
8	11.3	73
9	6	55
10	-0.1	51
11	-6.5	52
12	-10.8	39

The maximum rainfalls can be seen in of the Table 4 . The maximum rainfalls were in 1991 and 1992, in June and July reciprocally, with an average of 150 mm (Kersalo, 2009).

Table 4: Rains maximum per years and months, Rovaniemi city. (Kersalo, 2009)

Months	Rain’s maximum (mm)	Year
1	76	1983
2	61	1998
3	55	1989
4	62	1977
5	98	1983
6	150	1991
7	150	1992
8	140	1981
9	114	1975
10	101	1983
11	111	1996
12	80	1981

2.4. Introduction to activated sludge modelling

According to (Baeten, 2019) biological and physico-chemical reaction takes place in the ASM modelling, they are the important drivers for the bacteria removal. The biological conversions of substrates mean the growth of the biomass, thus this process is a degradation or a reaction of substrates which the final product of the biomass (Baeten, 2019).

Phosphorus removal can be divided into chemical, physical or biological. Biological removal through bio-removal (EBPR) is the most common method, chemical removal can also be used through metal salt addition and physical removal with a sorption method or ion exchange (Goel, 2013) . Phosphorus sources are sewage, industrial discharge or agricultural runoff, and tends to accumulate in the sediments (Goel, 2013).

The bacterial biomass suspension is responsible for the removal of pollutants. the removal of Nitrogen and phosphorus can be done with the help of activated sludge treatment.

The Figure **15** represents a lay-out of WWTP. the influent wastewater goes through one or multiple aerations tanks, then it goes to the clarifier. The clarified water goes to the effluent, solid sludge is collected to the sludge effluent. This pre-design will allow to make the equations and the unities needed in the process of WWTP.

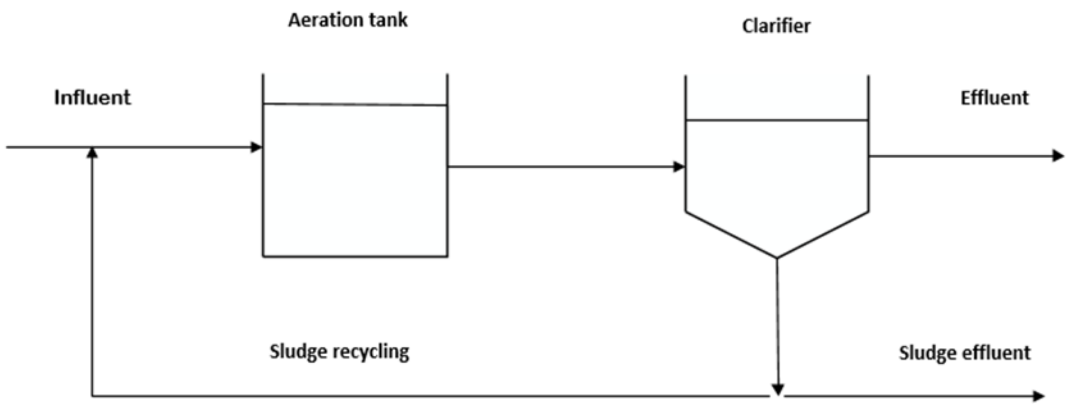


Figure 15: Activated sludge process.

According to (Coen, 1998), the main process design can be highlighted as:

- definition of the WWTP model (control, design, simulation)
- model selection: activated sludge models
- Hydraulics models for the WWTP tanks

- wastewater and biomass characterization and biomass sedimentation characteristics
- data reconciliation to a steady-state model
- calibration of the models
- scenario evaluations

2.4.1. wastewater characteristics.

The effluent of wastewater contains a different range of solids, which varies from rags to colloidal materials. The different solids present in wastewater are presented in Table 5 (Metcalf and Eddy, 2003). As seen in Table 5 below, there is different classification of the solids remaining in wastewater, also description of them and method of sampling them is represented. The method used is the evaporation of the sample at different temperature. Generally, the total solids (TS) are the residue remaining after sample of water has been evaporated and dried at about 1500c. (Metcalf and Eddy, 2003)

Total suspended solids

A paper filter is used to separate TSS from other solids, filters varies between 0.45 μm and 2 μm is used in the TSS test .The measured values of TSS depends on the type of pores of the paper filter (Metcalf and Eddy, 2003).

Table 5: Definition for solids found in wastewater (Metcalf and Eddy, 2003)

Test[b]	**Description**
Total solids (TS)	The residue remaining after a wastewater sample has been evaporated and dried at a specified temperature (103 to 105 ^{0}C)
Total volatile solids (TVS)	Those solids than can be volatilized and burned off when TS are ignited (500 ± 50^{0}C)
Total suspend solids (TSS)	Portion of the TS retained on a filter with specific pore size, measured after being dried at a specific temperature (105 ^{0}C). the filter used most for the determination of TSS the Whatman glass fiber filter, which has a nominal pore size of about 1.58µm.
Volatile suspended solid (VSS)	Those solids that can be volatized and burned off when the TSS are ignited (500 ± 50^{0}C)
Fixed suspended solids (FSS)	The residue that remains after TSS are ignited (500 ± 50^{0}C)
* Adapted from Standard Methods (1998)	

Volatile and fixed solids

As described in (Metcalf and Eddy, 2003), materials that can be volatized at 500 ± 50 ^{0}C is classified as volatile. Because of all organic matter will not burn at this temperature, so the residue is assumed to be as VFS.

In the activated sludge processes design the wastewater characteristics is very important and to be taken seriously. All concentration of wastewater components must be measured and calibrated before starting the design. From the Table 6 , we can see the average of USA wastewater characteristics. The COD concentration is about 430 mg/L, BOD and TSS concentration are 190 mg/L and 210 mg/L. The TKN and total phosphorus concentration are 40mg/L and 7mg/L. This data sure, can vary from one wastewater treatment to another, also it depends on the time season, winter or summer.

Table 6: Example of typical domestic wastewater parameters and values (Metcalf and Eddy, 2003)

Component	Concentration, mg/L*
COD	430
BOD	190
TSS	210
VSS	160
TKN	40
NH_4-N	25
NO_{3-N}	0
Total phosphorus	7
Alkalinity	200 (as $CaCO_3$)

*Typical medium-strength wastewater in USA

Dissolved oxygen

Dissolved oxygen is important for the bacteria and microorganism respiration and growth. Thus, for the aerobic bacteria. Oxygen is not highly soluble in water, so the concentration of oxygen in the WWTP is very crucial. WWTP also needs the oxygen to be added in different stage of the treatment of wastewater, one unit which used added oxygen is the Diffused air flotation. Discharge of organic pollutants can affect the level of DO in the wastewater treatment plants. Those pollutants´ origins in this case can be the effluents from residential, industrial wastewater or storm water from the sewage. The level of DO also depends on the temperature and on the bacterial concentration.

BOD

The biological oxygen demand is the amount of oxygen required for the growth of anaerobic bacteria to decompose organic matters. (USGS, 2020)

The bod provides the information about the readily biodegradable fraction of the organic load in water. This analytical method is time consuming, and the results may vary according to the laboratory (20%), because of fluctuations in the microbials diversity and difference in growth (Jouanneau, 2013).

Aerobic biodegradation consists of oxidizing organic matter biologically. As cited in (Jouanneau, 2013), the equation can be writing shown in equation 2, the presence of nitrogen, Phosphorus and mineral nutrients, can accelerate the rate of the transformation of initial biomass to a final biomass with release of Water and CO_2 .

$$X_0 + S + O_2 \xrightarrow{N,PMN} X_f + T_P + CO_2 + H_2O \qquad 2$$

X_0 Initial biomass

S Organic carbonic source

O_2 Oxygen

N Nitrogen

P Phosphorus

MN Mineral nutrients

X_f Final biomass

T_P Transformation products of biodegradation

CO_2 Carbon dioxide

H_2O Water

COD

The Chemical oxygen demand meaning is to define and resolve the need of organic matter in the WWTP. The COD allows to understand how much organic pollutants, bacterial cell or organisms is released to landfill or to rivers, lakes or to the sea. The eutrophication is results of mis understanding the release of organic matter to the water ecosystem. The non-elimination of the COD before reaching water sources. Can lead to the dead of aquatic life. Bacteria and microbe will consume the exceeded COD.

TKN

Nitrogen is very important if not essential in the growth of microorganism, such bacteria and microbes. Nitrogen is an essential element in the synthesis of proteins. In WWTP, control of algal growth, removal or reduction of nitrogen in wastewater prior to releasing or discharge is very crucial to aqua life (Metcalf and Eddy, 2003) .

As cited in (Metcalf and Eddy, 2003), in the Table 7, the total nitrogen is the sum of organic nitrogen, ammonia, nitrite and nitrate. The total Kjeldahl nitrogen is the sum of organic and ammonia nitrogen.

Table 7: Definition of Nitrogen in the WWTP (Metcalf and Eddy, 2003)

Form of nitrogen	Abbrev	Definition
Ammonia gas	**NH_3**	**NH_3**
Ammonium ion	$\boldsymbol{NH_4^+}$	$\boldsymbol{NH_4^+}$
Total ammonia nitrogen	**TAN***	**NH_3 + NH_4^+**
Nitrite	$\boldsymbol{NO_2^-}$	$\boldsymbol{NO_2^-}$
Nitrate	$\boldsymbol{NO_3^-}$	$\boldsymbol{NO_3^-}$
Total inorganic nitrogen	**TIN***	**$NH_3 + NH_4^+ + NO_2^- + NO_3^-$**
Total Kjeldahl nitrogen	**TKN***	**Organic N + $NH_3 + NH_4^+$**
Organic nitrogen	**Organic N***	**TKN – ($NH_3 + NH_4^+$)**
Total nitrogen	**TN***	**Organic N + $NH_3 + NH_4^+ + NO_2^- + NO_3^-$**

*All specifies expressed as N

PHOSPHORUS

Phosphorus is the major factor of water eutrophication, thus the legislation in many countries are pushing high the WWTP to reduce the influent concentration of phosphorus. The discharge of industrial and residential wastewater is controlled to avoid release of phosphorus. The main origin of phosphorus is human or animal faecal, detergents and cleaning chemical used by householders.

The usual forms of phosphorus as described at (Metcalf and Eddy, 2003), are orthophosphate, polyphosphate, and organic phosphate. The orthophosphate, $\boldsymbol{PO_4^{3-}}$, $\boldsymbol{HPO_4^{2-}}$, $\boldsymbol{H_2PO_4^-}$, $\boldsymbol{H_3PO_4}$, are ready for biological metabolism without further breakdown.

The Figure **16**, represents, the DNA structure, in which the phosphorus is primordial for the cell grow and reproduction (Song, 2011)

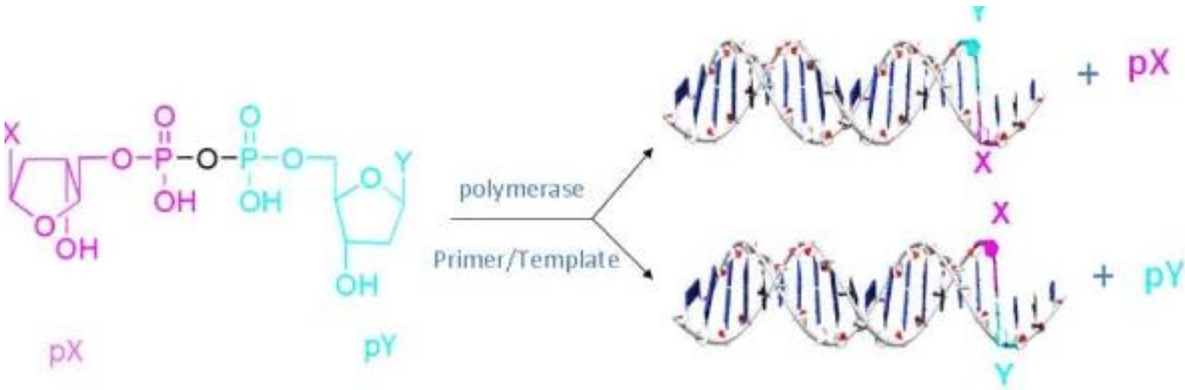


Figure 16: DNA structure (Song, 2011).

Biological treatment

The biological wastewater treatment means the use of microorganism to metabolize or to stabilize the organic matter presents it the WWTP. As described in (Metcalf and Eddy, 2003), in the equation, oxygen, ammonia, and phosphate are used to represent the nutrients needed for the conversion of the organic matter to simple end products. The term over the arrow means that microorganisms carry out the oxidation of process. For phosphorus removal, biological processes are simulated to growth bacteria. This process allows to digest and store a large amount of inorganic phosphorus (Metcalf and Eddy, 2003). as seen in the equation 3 , microorganisms, are also responsible for the Nitrogen digestion.

$$\boldsymbol{v_1\,(organic\ material) + v_2O_2 + v_3NH_3 + v_4PO_4^{3-} \xrightarrow{microorganisms} v_6(new\ cells) + v_6CO_2 + v_7H_2O} \quad (3)$$

Aerobic digestion treatment

At this step, after depleting available substrate, microorganisms start to consume their own protoplasm for their energy (Metcalf and Eddy, 2003). The results of this reaction are carbon dioxide, water and ammonia. For the simulation of the process, formula $C_5H_7NO_2$, can represent microorganism cell masses.

The equations,4,5,6,7 and 8 remaining at this step can be represented as below (Metcalf and Eddy, 2003):

Biomass destruction:

$$C_5H_7NO_2 + 5O_2 \longrightarrow 4CO_2 + H_2O + NH_4HCO_3 \quad \textbf{4}$$

Nitrification of released ammonia nitrogen:

$$NH_4^+ + 2O_2 \rightarrow NO_3 + 2H^+ + H_2O \quad 5$$

Overall equation with complete nitrification:

$$C_5H_7NO_2 + 7O_2 \rightarrow 5CO_2 + 3H_2O + HNO_3 \quad 6$$

Using nitrate nitrogen as electron acceptor (denitrification):

$$C_5H_7NO_2 + 4NO_3^- + H_2O \rightarrow NH_4^+ + 5HCO_3^- + 2NO_2 \quad 7$$

With complete nitrification/denitrification:

$$2C_5H_7NO_2 + 11.5O_2 \rightarrow 10CO_2 + 7H_2O + 2N_2 \quad 8$$

2.5. WWTP modelling and simulation

The effluent of WWTP flowrates and concentration is very important for the work of the plant. Modelling is an inherent part of the design of a wastewater treatment system, regardless of the approach used (Henze, et al.). For the processing of the organic matter in the effluent, activated sludge is used because of its low price comparing to the use of chemical treatment to neutralize pollutants (Henze, et al., 2002).

Generally, modelling a wwtp is a very difficult target, especially a mathematical model, even they resent a simplification of reality (Jeppsson, 2005). The wwtp processes are very complex and includes physico-chemical and biochemical processes, the mean role is of the bacteria metabolism which means the capability of microorganism to reduce and digest organic substances (Laizāns, 2012).

One of the earlies studies about wwtp and ASM is cited at (Alex, 1999),the authors used the Simba software process which data was managed by MATLAB, ,they insists that on-line models offers the possibility to operate wwtp easily, the models can acts as an observer on line to control the entire processes (Alex, 1999).

The modelling of activated sludge models is one of the most importing part for the Wastewater treatment simulation and building of the wastewater treatment plants process plant. Before starting the modelling, the simulations, must be done in order to make an idea about the workability. The Activated sludge model is the most important part of the WWTP simulation and design. In this unit, takes part the COD, BOD, Nitrogen, Ammonium, Phosphorus elimination or neutralization. The effect of extreme weather on the function of wastewater treatment plants is very high. With the last decades temperature increasing and the sea or ocean level increasing, are influencing the re-design of units and the sites of the wastewater treatment plants in different part of the world.

Different approaches had been made by different methods. Methods used vary from mathematical models of activated sludge modelling or using MATLAB software for mathematical modelling or some specific WWTP software programs.

2.6. Software used in WWTP modelling and simulation.

Different methods exist for the WWTP simulation. In this part will be discussed some software used in the WWTP simulations.

2.6.1 MATLAB®.

MATLAB is mathematic software allowing multiple simulation through different equation. It can also be used in WWTP simulation. Knowing the mass balance and using differential equation and boundary condition which will be derived. (David, et al., 2009)

Simulink is a block diagram environment for multidomain simulation and model/based design. It supports dynamic modelling and design. Because of its supports system, it allows the design, the simulations, and continuous test and verification. It uses also linear and nonlinear system.

According to (David, et al., 2009) , WWTP parts can be simulated with MATLAB Simulink, also, partial differential equations (PDES) can be solved with Simulink. For the modelling in this article was used differential equation and boundary conditions was derived after that.

2.6.2. Water Quality Analysis Simulation Program (WASP).

WASP is software used for simulation of the effluent of WWTP. It does not include the modelling or simulation of the WWTP itself but allows to study and compare the effluent of the WWTP. According to the developer's web site, WASP helps understand and the prediction of water quality to make decision on this prediction. It allows to study 1, 2 and 3 dimensional systems, plus diverse pollutants. Some studies conducted with this software are (EPA; United States Environmental Protection Agency., 2020):

- Eutrophication of Tampa Bay, FL, USA.
- Phosphorus loading to Lake Okeechobee, FL, USA.
- Volatile organic pollution of the Delaware Estuary, USA.

Figure **17**, shows the modelling of the WWTP simulation. The software allows to integrate biochemicals sewers models with WWTP models, in order to simulate the water effluent qualities (Guo, 2019)

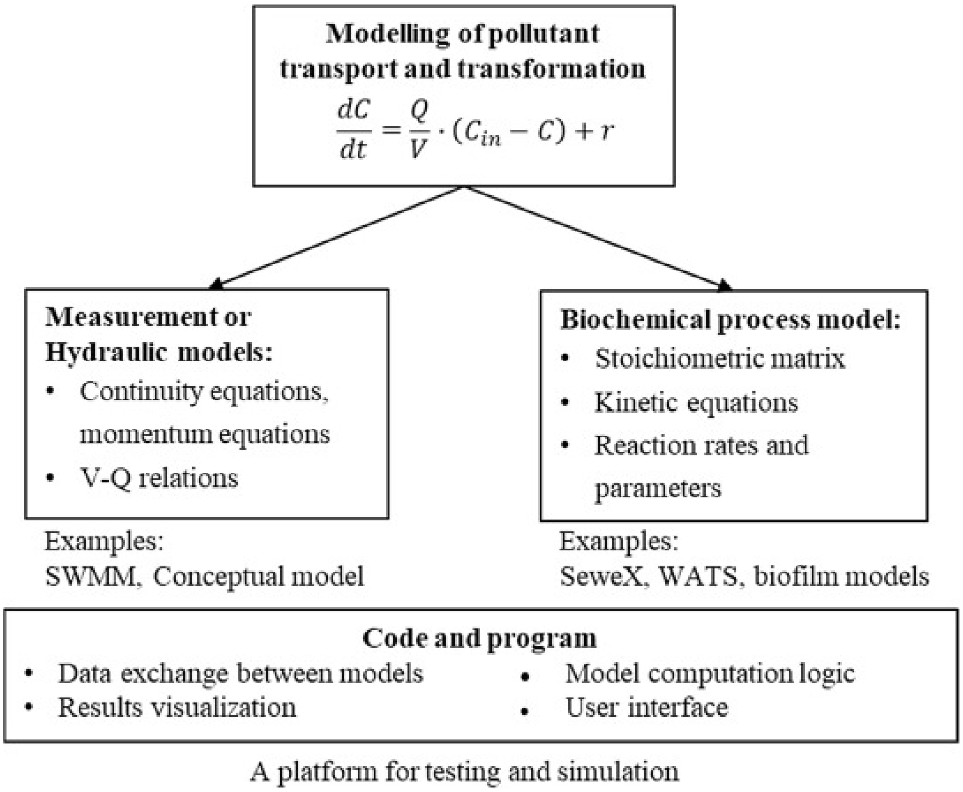


Figure 17: Scheme of pollutant in sewers systems (Guo, 2019)

An example of WWTP simulation results, is shown in the Figure **18**, (Guo, 2019). It explains the distribution of total dissolved sulphide for the Québec city.

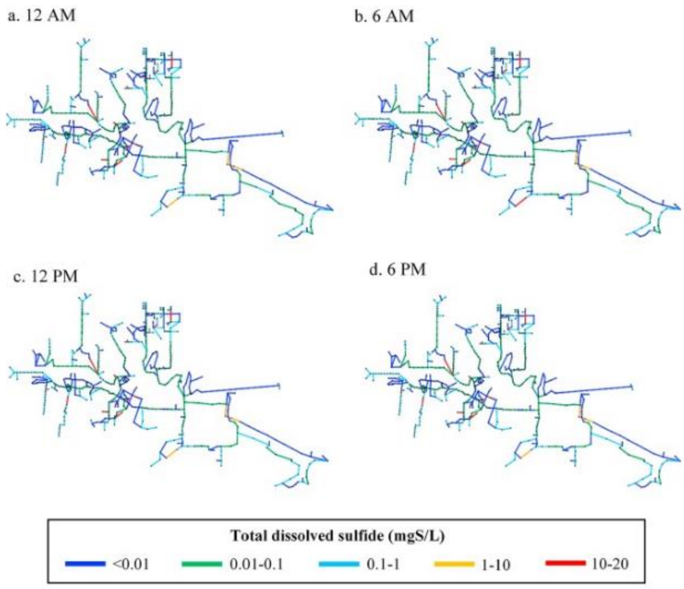


Figure 18: Distribution of total dissolved Sulfide for the city Québec case study (Guo, 2019).

2.6.3. GPS-X software.

GPS-X is very strong software for the WWTP analyses. As cited in the software web site, the GPS-X is WWTP and modelling software. It is a whole plant model allowing to analyse BOD, Nitrogen and phosphorus removal (hydromantis, 2020).

2.6.4. Mathematical simulation.

Analysis of the activated sludge model can be also simulated with some free mathematical software's. To make possible these simulations, the model consists of differential equations for the chemical concentrations in the reactor.

2.6.5. West simulation.

WEST is a software used for dynamic modelling and simulation of WWTP. Typical use for the software is: Evaluation of WWTP design, Process optimization, Model calibration. The Figure **19**, shows details for the process optimization. (Mike powerd by dhi, 2020).

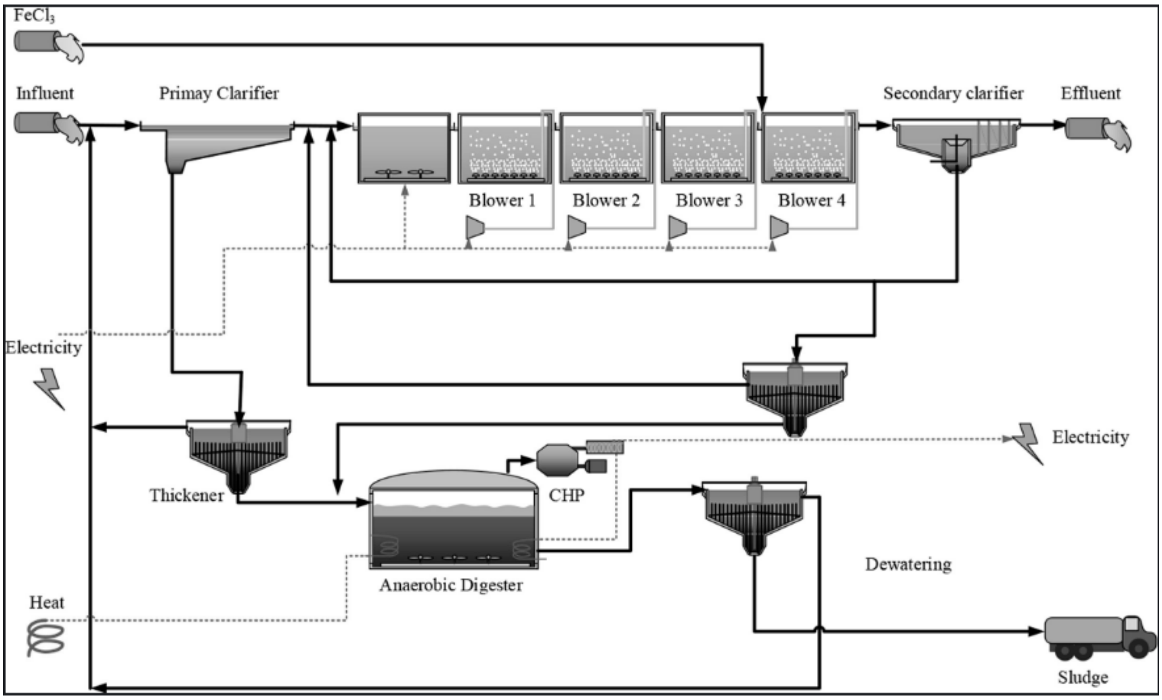


Figure 19: West software interface (Mike powerd by dhi, 2020).

2.5.6 BioWin.

BioWIN is a software used to design and simulate wide plant of WWTP. The figure shows an example of the WWTP simulation, Figure is demonstrating the user´s interface for BioWIN software.

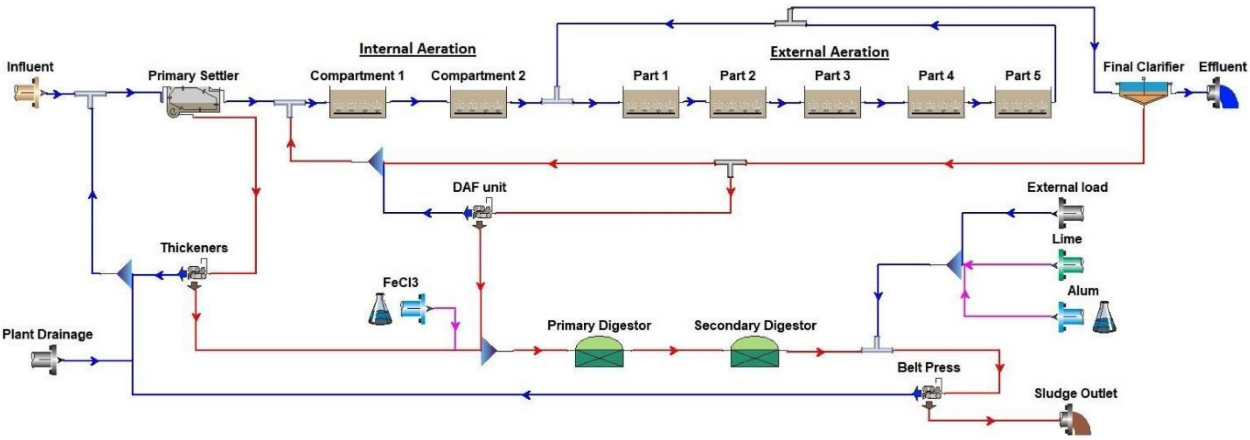


Figure 20: BioWin software interface (Elawwad, 2019).

2.6.7 Steadystate.

Steadystate is a free software for the WWTP simulation, even if it is limited for only the nitrification simulation, is still a good software for users. **Error! Reference source not found.**, shows the user´s interface of the Steadystate software. In experimental part will be discussed more about the steady state software.

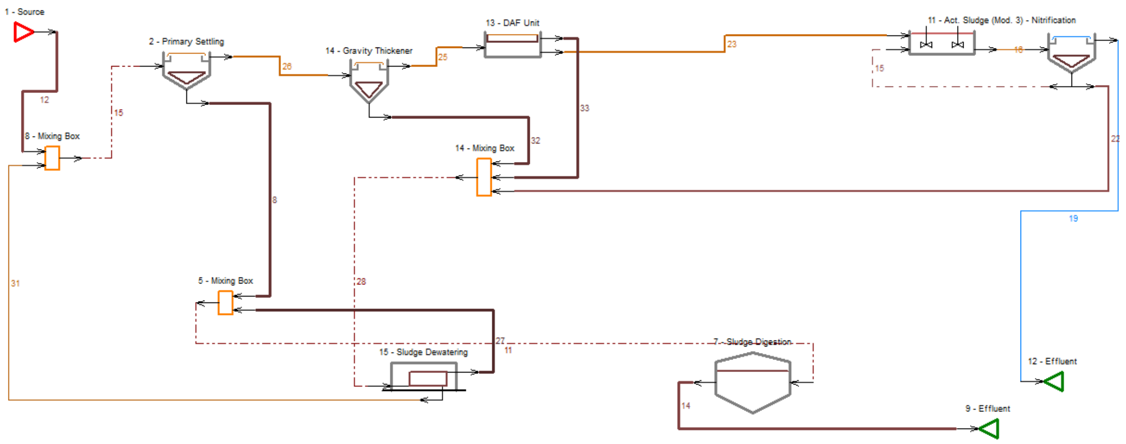


Figure 21: Steady state user interface.

2.7 Stormwater and runoff characteristics

No one technology or management control will resolve all water or stormwater management problems, modern stormwater system design can decrease runoff and increase the ground infiltration which will improve the runoff water quality (NRC, 1993). The rainfall loads are not constant, but intermittent, pulsed loads, the pollutant concentration are dramatically very large during runoff (NRC, 1993). Thus, the prediction of pollutant concentration will be difficult to predict the ideal remediation, this will directly impact the water sources as the work of the WWTP facilities.

The fact that urban stormwater needs a treatment to improve its quality is well recognized, it also known that intensive urbanization and paving activities reduces the infiltration of stormwater and promote a rapid runoff (TRAFIKVERKET, 2018). Table shows references values of pollutant concentrations in runoff roads, the volume of road runoff, sure, dependents on some factors as infiltration capacity of the road and the embankment (TRAFIKVERKET, 2018). The Table **8** represents the standard values of pollutants in stormwater.

Table 8: Standard values for concentrations of pollutants in stormwater and percentages of dissolved fraction in stormwater from mixed urban areas (TRAFIKVERKET, 2018).

Parameter	Unit	15000- 30000 ADT[1]	>30000 ADT[1]	Dissolved fraction in stormwater[2]
Phosphorus	**(mg/L)**	**0.20**	**0.25**	**5-80%**
Nitrogen	**(mg/L)**	**1.5**	**2.0**	**65-100%**
Lead	**(µg/L)**	**25**	**30**	**1-28%**
Cupper	**(µg/L)**	**45**	**60**	**20-71%**
Zinc	**(µg/L)**	**150**	**250**	**14-95%**
Cadmium	**(µg/L)**	**0.5**	**0.5**	**18-95%**
PAH	**(µg/L)**	**1.0**	**1.5**	**10-15%**
Suspended solids	**(mg/L)**	**100**	**1000**	**-**

[1]Trafikverket (2011), [2] Larm & Pirard (2010)

Stormwater characteristics

Development had and is transforming water balances and water quality in different ways as described below (USEPA, 2001):

- Changes in Hydrology
- rising water pollution and nutrients
- rising water acidity
- Higher water temperature
- Changes in Hydrology

In a study of 40 runoff monitoring sites across the USA, a 1-acre (4047 m^2) parking lot was found to produce a runoff volume almost 16 times as large as the runoff volume produced by an undeveloped meadow (USEPA, 2001). Furthermore, sediments pollutants load from erosion increases costs for water treatment and accumulation of pollutants (USEPA, 2001).

Increased water pollution and nutrients.

Stormwater is usually polluted by pesticides and fertilizers from householders, farms also heavy metals, antifreeze, lead, oxidized hydrocarbons from vehicles, oil, urban debris (USEPA, 2001). Urban runoff contains significant pollutants as heavy metals, salts and hydrocarbons, understanding the interactions between pollutants particles and their impacts on water is crucial to develop an appropriate treatment for the runoff (Hilliges, 2017). the impact of surface stormwater runoff on the waterbodies is very big, runoff is usually collected in a stormwater system, which is not always cleaned, the most common method of cleaning is sedimentation or separation (Babko, 2019) .Acidity can increases in times, SO_2 especially from electric utilities fired by coal , or nitrogen oxides (NO_x), emitted by transportation sources and utilities, are deposited in the form of wet or dry deposition (USEPA, 2001). Higher runoff volumes increase the pollutants volumes on the receiving streams (USEPA, 2001). This can impact the work of the wastewater treatment facilities. Especially when the compounds of stormwater are unknown, and a WWTP needs all wastewater pollutants to be known.

From the Table 9 we can see that stormwater pollutants are a very wide spectre, from nutrients as Phosphorus, Nitrogen and phosphorus, to heavy metals, Viruses, bacteria, particulates and sediments.

Table 9: Pollutants in stormwater (Holt, 2018)

Source	Main pollutants	Details
Atmospheric deposition	**Phosphorus, nitrogen, Sulphur, metals, hydrocarbons, particulates**	**Industrial activities, traffic exhaust fumes, agricultural activities. Rain absorbs atmospheric pollutants which then end up in the stormwater surface runoff. Atmospheric pollutants can be deposited on roofing materials and discharged into roof runoff**
Traffic –exhaust fumes	**Hydrocarbons, nitrogen, phosphorus, cadmium, platinum, palladium, rhodium**	**Emissions include polycyclic aromatic hydrocarbons, metals, particulates and other chemical components of incomplete fuel combustion.**
Traffic – wear and corrosion	**Particulates, metals, hydrocarbons**	**Abrasion of tyres, corrosion of vehicles and asphalt wear de-posit pollutants on roads.**
Animal faeces, sewer overflows and septic system leaks	**Bacteria, viruses, phosphorus, nitrogen**	**Pollutants in uncollected animal waste wash off urban surfaces with runoff. Dead animals (e.g. roadkill) and pet faeces release bacteria into the stormwater. Sewer overflows and septic system leaks release untreated wastewater and associated pollutants**
Litter and debris	**Gross pollutants**	**Clogging hazard for surface runoff collection systems. Sources include pedestrians and vehicles, waste collection systems, leaf litter from trees, lawn clippings, etc**
Building construction	**Gross pollutants, particulates (sediment), hydrocarbons, metals.**	**Site disturbance and heavy equipment use during building activities, together with vehicle traffic on site, results in high suspended solids content of stormwater surface runoff from building sites, along with hydrocarbons and metals, and may also contain gross pollutants**
Weathering of buildings and structures	**Particulates**	**Variable in both extent and in the composition of particulates, physical and chemical weathering processes result in release of particulate solid materials from building surfaces.**
Farming/landscape maintenance	**Phosphorus, nitrogen, herbicides, insecticides**	**Herbicides and pesticides used for weed and pest control in landscaped areas. Nutrients used in farming cause eutrophication in receiving waterbodies**
De-icing activities	**Chloride, particulates**	**Salts used for de-icing roads contain chlorides. Gritting (use of gravel or sand) increases the suspended solids content of stormwater surface runoff**
Cleaning activities	**Particulates, phosphorus, nitrogen, surfactants, hydrocarbons**	**Pressure washing vehicles, windows, bins etc. leads to silt, organic matter, detergents and hydrocarbons entering the sur-face water drainage**

For a study about the of stormwater and runoff effect on wwtp, concentration of pollutants was collected from different sources (Welker, 1999) and is presented in Table 10, But here the authors did not mention the origin of NH_4-N measurement. Ammonia can originate from nitrogenous waste from industrial utilization, fertilizers, municipal waste and other natural or human activity. In dry weather flow´s concentration is higher in times than the wwtp effluent and higher than the street runoff and runoff concentrations.

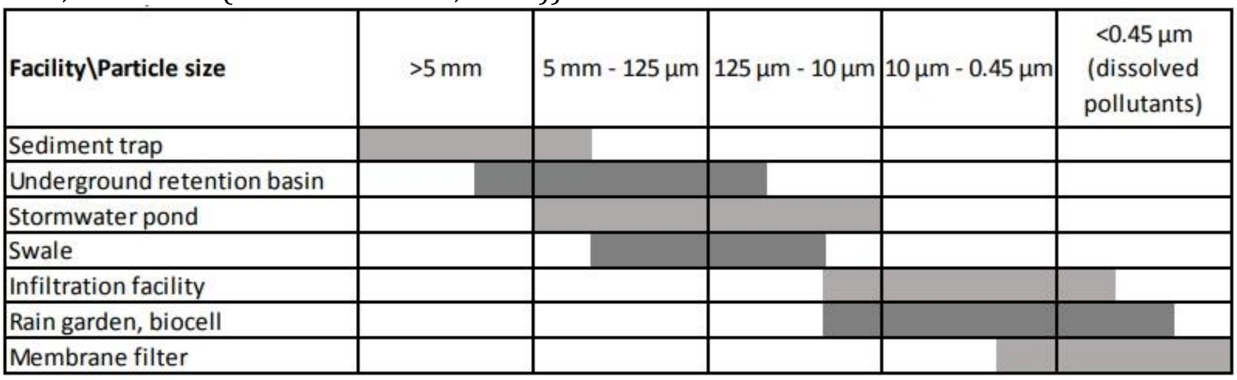
Table 10: Concentrations of various parameters in dry weather flow, WWTP effluent and different surface runoffs (Welker, 1999)

	Concentration (mg/L)					
Parameter	**COD**	**BOD**	**SS**	**NH_4-N**	**Cu**	**Pb**
street runoff	**100**	**30**	**600**	**1**	**0.1000**	**0.140**
roof runoff	**30**	**10**	**50**	**1**	**0.200**	**0.070**
dry weather flow	**600**	**300**	**280**	**35**	**0.150**	**0.100**
WWTP effluent	**60**	**10**	**20**	**10**	**0.0.030**	**0.020**

2.8. Stormwater and runoff treatment.

The Table 11, shows the treatment recommended for different particle sizes ranges. The smallest the particle´s size the difficult is to treat it and proceed it, due to the method used. The smallest is the particle, the most expensive method is used as membrane filters.

Table 11: Table Suitability of treatment methods according to particle size ranges (Blecken, 2016, as cited in (TRAFIKVERKET, 2018)).



The studies were conducted in a fictional catchment (100 ha) with a population of 5000 inhabitants, the surface was divided into two (2) parts, the center and the outskirts. The surface was divided in different part according to its utilization (roofs, roads, parking, green.) (Welker, 1999).

3. ASM1, ASM2 and ASM3 history and analyses.

Activated sludge model is focusing on the removal of the biological Nitrogen and Phosphorus. Historically models were developed from ASM1 through ASM2 till the last model ASM3. According to (Henze, et al., 2002), ASM models were developed to be more complex from ASM1 that includes the Nitrogen removal, to ASM2 which consists of phosphorus removal. The ASM3 includes both former models and their development.

3.1. ASM1

The process of the Activated sludge modelling, ASM consists of model of biological reactors which can be more than one reactor and a settler. ASM1 was first made and developed for the removal of organic carbon compound and Nitrogen from municipal activated sludge wwtp. It was concluded that Chemical Oxygen Demand (COD) is A good measure of the COD for the delay of the organic matter (Gernaey, 2004). Asm1 was developed for municipal activated sludge wwtp to explain the remediation of carbon compounds and Nitrogen in its different states (Iacopozzi, 2007) . All the ASM models target is the removal of ammonia, in those processes, bacteria are involved in the denitrification-nitrification process. The bacteria are also in contact with nutrient as phosphorus or nitrogen in its different formats. The ammonia and nitrate are reduced to nitrogen gas the released to the atmosphere. Oxygen is added to the process throughout a diffused air tank. Usually, no other chemicals are added to the process. The ammonia is digested by bacteria, then they form flocculates which settles to the bottom of the reactor. Due to sedimentation, the flocculants solids are easy to remove the returned to the to the aerated reactor. The settler or in other words the clarifier condensate the micro-organism responsible for the digestion of ammonia and nitrates. The ASM1 and ASM2 simulation are conducted with calculation of the COD and TSS concentrations.

As described at (Grau, 1983), constituents of the influent which are insoluble are given symbol *X* which means the particulate material concentration , soluble are given the symbol *S*, which means the total material concentration, is assigned to each compound and j for each process. The proposed initials for WWTP simulation are cited at (Grau, 1983). Table 12, represents the initials recommended for use in WWTP simulation and calculation (Grau, 1983).

Table 12: Initials used in wastewater treatment. (Grau, 1983)

Symbol	Quantity name or names	* Dimension	Footnote
ϵ	Intergranual porosity or void volume fraction	— (from L^3L^{-3})	
X	Particulate material concentration	M_iL^{-3}	1,2
S	Soluble material concentration	M_iL^{-3}	1,2
C	Total material concentration (particulate plus soluble)	M_iL^{-3}	1,2

The Table 13 (Henze, et al., 2002), represents the process kinetics of mass balance of WWTP. The process, growth and decay are given functions, for different situation as for biomass, substrate or oxygen COD.

Table 13: The process kinetics of mass balance of WWTP. (Henze, et al., 2002)

Continuity →

Mass Balance ↓

Component → i / j Process ↓	1 X_B	2 S_S	3 S_O	Process Rate, ρ_j $[ML^{-3}T^{-1}]$
1 Growth	1	$-\frac{1}{Y}$	$-\frac{1-Y}{Y}$	$\frac{\hat{\mu}S_S}{K_S+S_S}X_B$
2 Decay	−1		−1	bX_B
Observed Conversion Rates $ML^{-3}T^{-1}$	$r_i=\sum_j r_{ij}=\sum_j \nu_{ij}\rho_j$			Kinetic Parameters: Maximum specific growth rate: $\hat{\mu}$ Half-velocity constant: K_S Specific decay rate: b
Stoichiometric Parameters: True growth yield: Y	Biomass $[M(COD)\,L^{-3}]$	Substrate $[M(COD)\,L^{-3}]$	Oxygen (negative COD) $[M(-COD)\,L^{-3}]$	

Thus, equations **9** for the mass balance are (Henze, et al., 2002):

$$\textbf{Input} - \textbf{Output} + \textbf{Reaction} = \textbf{Accumulation} \qquad \textbf{9}$$

The system reaction 10 term is obtained by summing the products of stoichiometric coefficients and the process rate expression for the component being considered in the mass balance (Henze, et al., 2002).

$$r_i = \sum_j v_{ij} \rho_j \qquad \textbf{10}$$

According to (Henze, et al., 2002) , the equation 11 represents the reaction, $\boldsymbol{r}$, for biomass, $\boldsymbol{X_B}$, at a point in the system in the system would be:

$$r_{X_B} = \frac{\mu^{\wedge} S_S}{K_S + S_S} X_B - bX_B \qquad \textbf{11}$$

3.2. ASM2

The Activated Sludge Model N0 2, ASM2, is an extension of ASM1, (Henze, et al., 2002). It is a model for biological eradication of phosphorus, it also includes a reaction of nitrification and denitrification. The effect of phosphorus on the water organism is crucial, it reduce the DO concentration which allows the grows of algae in surfaces where wastewater effluent is released. The irradiation of phosphorus is energy and time consuming. The removed phosphorus is usually released to downfall land or collected with soil and sold as fertilizer. Phosphorus is collected from sedimentation tank then collected.

Different processes for phosphorus removal are used. They are biological chemical or hybrid using both biological and chemical.

Asm2 model has also an extended version, with the extracellular polymeric substances (EPS) in phosphorus removal in an anaerobic-aerobic process (Yang, 2017). for the model two new components were added, the bound EPS(X_{EPS}), and the soluble EPS(S_{EPS}), and according to (Yang, 2017), the EPS can increases the removal of Phosphorus in Biological phosphorus (BPR)

3.3. ASM3

The Activated sludge model N0 3 ASM 3, includes the quantification of energy storage to describe substrate and oxygen uptake with high accuracy.

The ASM3 is a model of biological reactions in anaerobic granular sludge (SBR), in this model the effluents COD, $\boldsymbol{NH_4^+ - N}$, and TN toward the stochiometric and kinetic coefficients (Zhou, 2013). The ASM3 assumes that the nitrification and denitrification are a single-step processes (Zhou, 2013), which means in simulation each equation can be calculated and estimated separately.

In this ASM3 (Bournazou, 2010), a two-step reaction is simulated, the nitrification and the denitrification. These reactions **12** and **13** take place in sequence batch reactor. Aerobic and anoxic phase or in other words, are the nitrification and denitrification processes needed to remove ammonia from the WWTP. First ammonia is transformed to nitrate in an aerobic process. Then in the anoxic step, microorganisms transform the nitrate in nitrogen. The figure represents the two-step reaction of nitrification-denitrification.

$$\boldsymbol{NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-} \qquad \mathbf{12}$$

$$\boldsymbol{NO_3^- \rightarrow NO_2^- \rightarrow N_2} \qquad \mathbf{13}$$

The Figure 22 shows the two step of nitrogen fixation-nitrification. The bacteria used to transform the Nitrogen to NH_3, then bacteria as an oxidizer transform NH_3, to NO_2^- . The next step is the Nitrite oxidization by bacteria to NO_3^-. The last step is the transformation of NO_3^* to NH_4^+ (Stein, 2015).

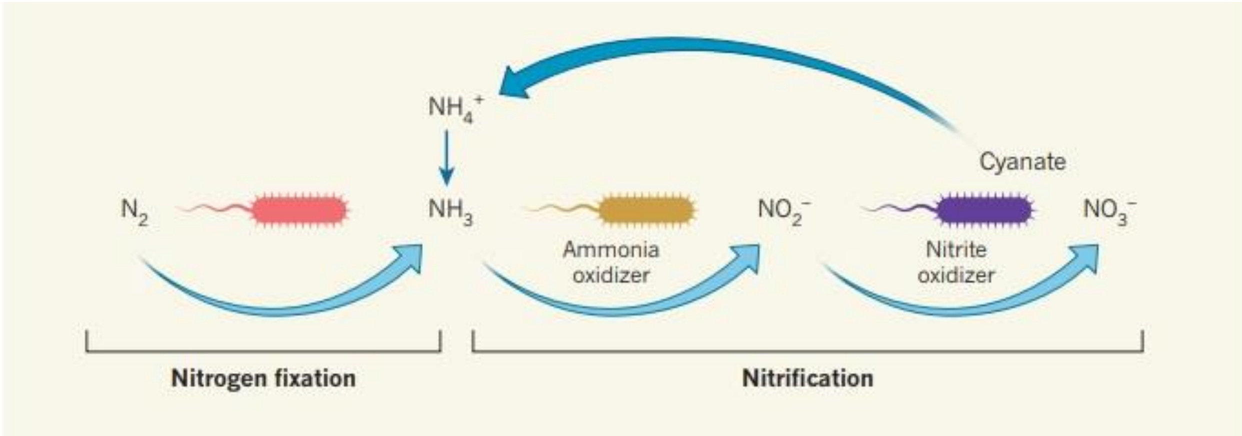


Figure 22: The two step processes of nitrification-denitrification (Stein, 2015)

4. Experimental part

In this chapter, a model of simulations and analyses of activated sludge model will be discussed. The Turku´s WWTP works, and processes will be as an example of simulations.

The main objectives of this work were to design and simulate the work of a wastewater treatment plant. This work will focus on the design of the Activated sludge model 3. The data was collected from the Turku´s wastewater treatment plant, which is situated in south-western of Finland. The data contains the average of compounds contained in the effluent of the WWTP and the average measurement of the compounds.

An approach for the activated sludge model is done in this work with the Steady state software. It is a software made by the university of for WWTP simulation. The simulation was done with overpass of hydraulic loads of wastewater, in case of flood or another extreme situation. A layout was designed in Steady state software, corresponding to the Turku WWTP layout.

The simulation was made with different influent flow in L/s. The calculation was made, then analyzed.

4.1. Methods black box experimentation data.

The Kakolanmäki wastewater treatment plant is situated in the city of Turku, south-west of Finland. The WWTP is situated underground, and all facilities and unit are also constructed in the underground. In this work. The influence of temperature and the removal of phosphorus were not taking in consideration in this work. However, the data of phosphorus contaminant in the influent was given. The figure below represents the WWTP, which is uncommon in the order of its construction in the underground.

The data were collected to compare flows with different flow rates and concentrations, of contaminants.

4.2. Turku wastewater treatment plant.

The Kakolanmäen wastewater treatment plant is a company owned by 14 cities and counties in the South-west of Finland. The company is responsible for the work of the WWTP. The plant treats the wastewater of almost all the 300 000 inhabitants of this region. Also, it proceeds the industrial wastewater of this region.

The Figure **23**, represents the Turku´s wastewater treatment plant. The influent comes through a pumping station then coarse screening at which all metallic or large pollutants are removed. The sand separation units allow to remove all sand and small gravels. The fine screening separates all the small sands and plastics or metal pieces. From the primary clarifier the flux goes through the aeration tank. The next step is secondary clarifier after that the flux is directed to the sand filtration where all possible residues are separated then effluent is pumped to the Aura River. Also, the plant had a by-pass step, when extreme raining comes, which can exceed the plant´s capacities.

One of the most important steps in the WWTP, is the coagulation and flocculation. Coagulation allows the removal of phosphorus and suspended solids. Chemicals used are iron coagulant or aluminum coagulant. Ferrous chloride, ferrous sulphate or ferrous chloride sulphate are used. Aluminum's chloride or aluminum sulphate or sodium aluminate are also used. The use of coagulants grants the removal of organic pollutants especially in colloidal form.

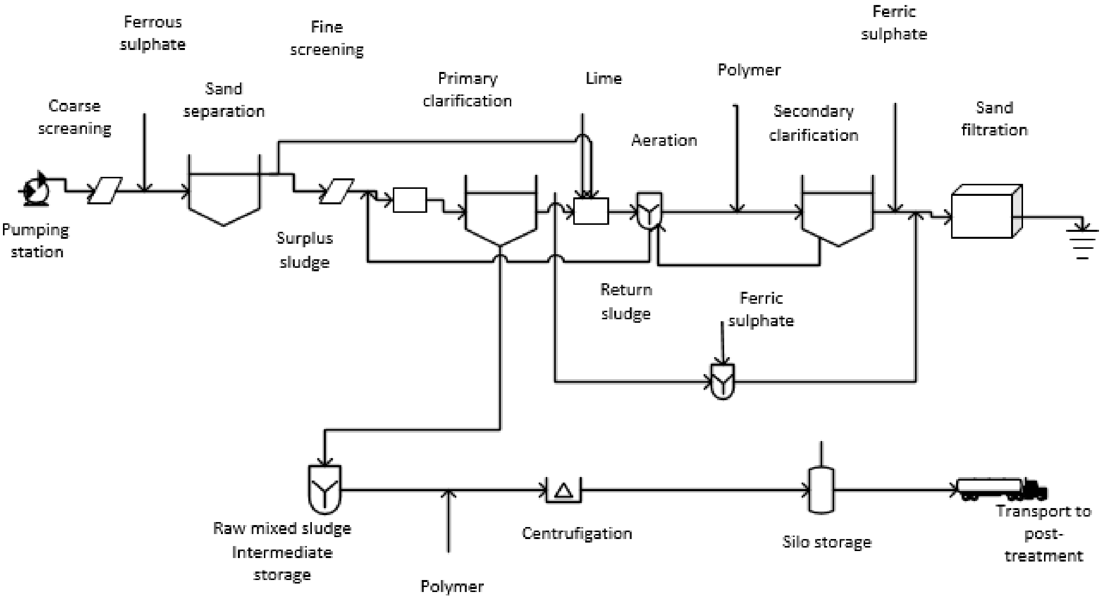


Figure 23: Turku wastewater treatment plant, adapted from company figure

The Figure 24, represents the map of the region of the Turku WWTP area. It is in the south-west region of Finland. It shows all the municipalities which are actioner of the relevant WWTP. The percentage means the real-time shares of the region of wastewater treatment plant effluent. As we can see, Turku city has the highest percentage of 62%, because of its inhabitants' number.

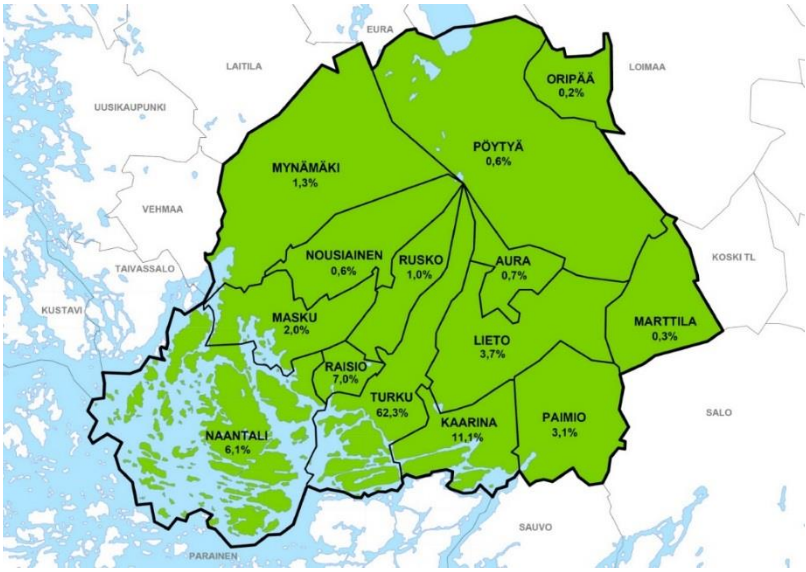


Figure 24: The Turku's region and cities percentages of WWTP influent (Lounas-Suomen vesi- ja ympäristötutkimus Oy, 2018).

The Figure 25, represents the checking point of water quality and the discharge place for wastewater and cooling wastewater. Because of the influent is pumped to the Aura River, the environment department make some checking of the water quality in some different points. According to this map the first control point is the influent of the Aura River, which can be used as reference. There is no WWTP before this point. There is multiples control point for the water after the discharge. Before effluent coming to the Turku´s Archipelagos, the water quality is controlled.

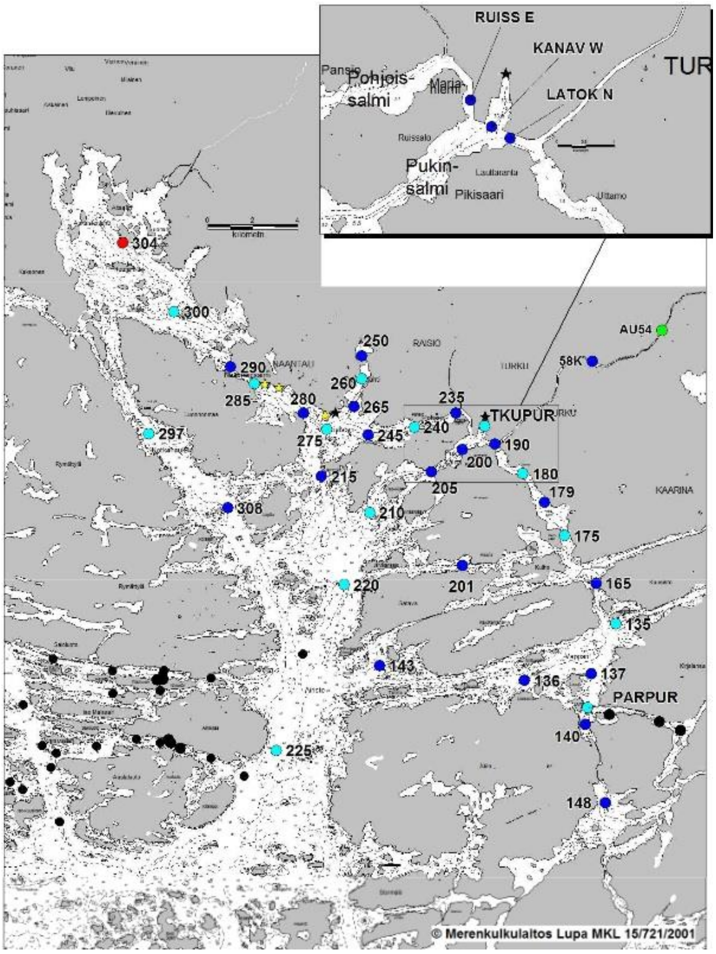


Figure 25: Control point of the Turku´s region (Suunnittelukeskus Oy, 30.11.2005).

- Water quality control points.
- Intensive water control.
- Not in use.
- Aura river control point.
- Other control points.

* Wastewater discharge place.

* Cooling water discharge place.

The Table 14 is representing the 2030-year target of the Turku WWTP flows and chemical loads.

As seen from the Table 14 , the average flow of the Turku WWTP, is about 120000 m3/d. The BOD and the COD values are reciprocally, 22000 and 52000 kg/d. The total sludge concentration is 33000 kg/d. The Phosphorus and total Nitrogen loads are reciprocally 760 and 4200 kg/d.

Table 14: Flows and chemicals load of the Turku WWTP (Suunnittelukeskus Oy, 30.11.2005)

Parameters	value	unit
Average flow rate/ day	120000	m3/d
Average flow rate/hour	5000	m3/h
Daily average flow rate	6000	m3/h
Maximum flow rate/day	275 000	m3/d
Maximum biologic processed flow rate	173 000	m3/h
MAXIMUM pre-treated flow	13 750	m3/h
Maximum biological primary treated	7700	m3/h
Maximum sand filtration flow rate	13750	m3/h
Maximum rejection flow rate treated by Actiflo®	8000	m3/h
BOD7 LOAD	22000	kg/d
COD load	52000	kg/d
Phosphorus load	760	kg/d
Nitrogen load	4200	kg/d
Total sludge load	33000	kg/d
Population equivalent	315000	inhabitants

The Figure 26, shows the rainfall amount during the year in the region of Turku. According to the figure we can see that the rain is falling not equally during the year. There are some peaks, especially in the begging of Jun, also in the end of July as in the end of November. It is only one day or two days peak. The most rainfall time is concentrated between the middle of January till the end of February. Also, there is other two important peaks in August and in the end of November. From the graph below we can see the picks of the effluent which exceeds in times the limit of the deigned WWTP units.

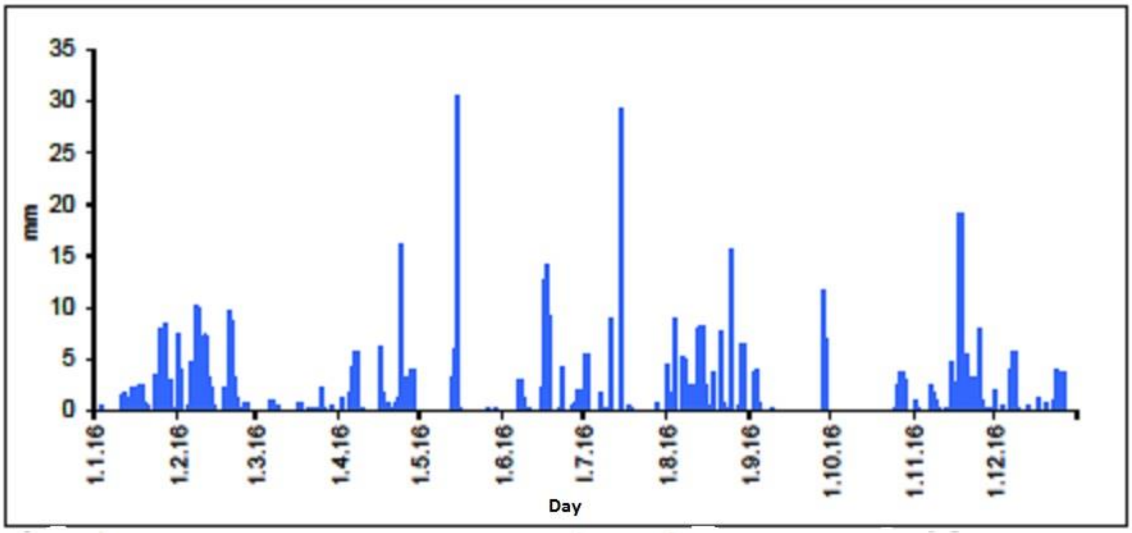


Figure 26: Rainfall average in the Turku region, Finland. (Lounas-Suomen vesi- ja ympäristötutkimus Oy, 2018)

The Figure 27, shows the quantity of the wastewater treated and the amount by-pass flow from the Wastewater plant of Turku.

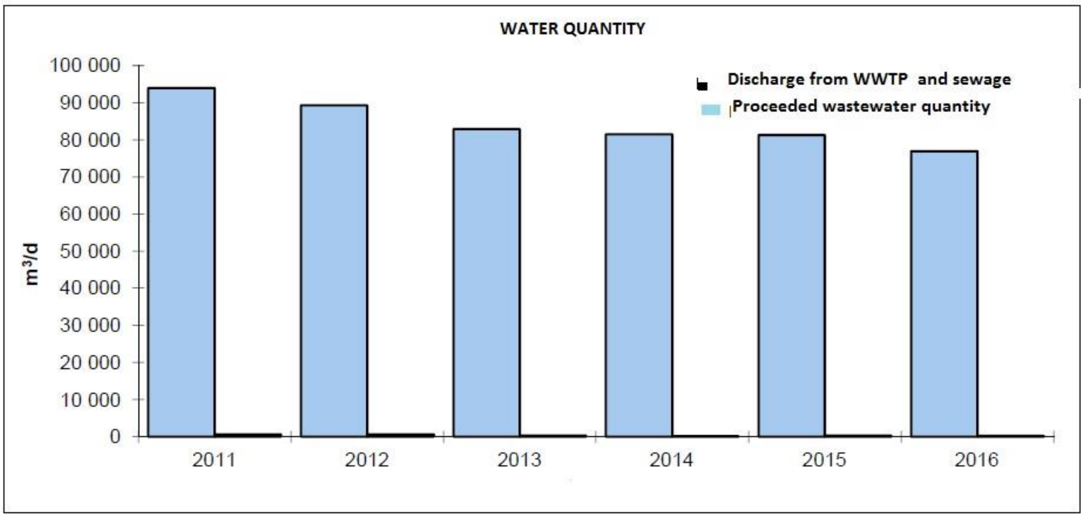


Figure 27: Quantity of wastewater treated by the Turku wastewater plant and by-pass flow as m^3/d (Lounas-Suomen vesi- ja ympäristötutkimus Oy, 2018)

The Table 15, represents the percentage of the Turku system of collecting stormwater. As Turku is the biggest city in this region, the percentage of the stormwater is the higher, around 70%, then come the city of Kaarina and Raisio with about 10%. We can see that the feeds did not change a lot in the years.

Table 15: Percentage of feeds of the stormwater by community by year. (Lounas-Suomen vesi- ja ympäristötutkimus Oy, 2018)

		2011	2012	2013	2014	2015	2016
Turku	%	68.6	68.5	68.9	68.5	67.9	67.4
Kaarin	%	8.8	9.1	8.8	9.3	8.3	9.4
Lieto	%	2.3	2.6	2.9	2.4	2.9	2.8
Rusko	%	0.8	0.6	0.7	0.9	0.9	0.9
Paimio	%	3.5	3.8	3.2	3.2	3.3	2.9
Raisio	%	9.2	8.8	8.4	8	7.9	7.6
Naantali	%	3.7	3.9	4	4.2	4.4	4.5
Masku	%	1.1	1.08	1.1	1.5	1.5	1.5
Nousiainen	%	0.7	0.7	0.8	0.6	0.7	0.7
Mynämäki	%	1.2	1.05	1.2	1.2	1.4	1.2
Aura	%					0.7	0.7
Pöytyä	%					0.04	0.5
Oripää	%					0.02	0.03

From the Figure 28 we can see that the flow (m3/d) has two peaks. The highest peak is in the end of January till the middle of February. The second peak is between April and the middle of May.

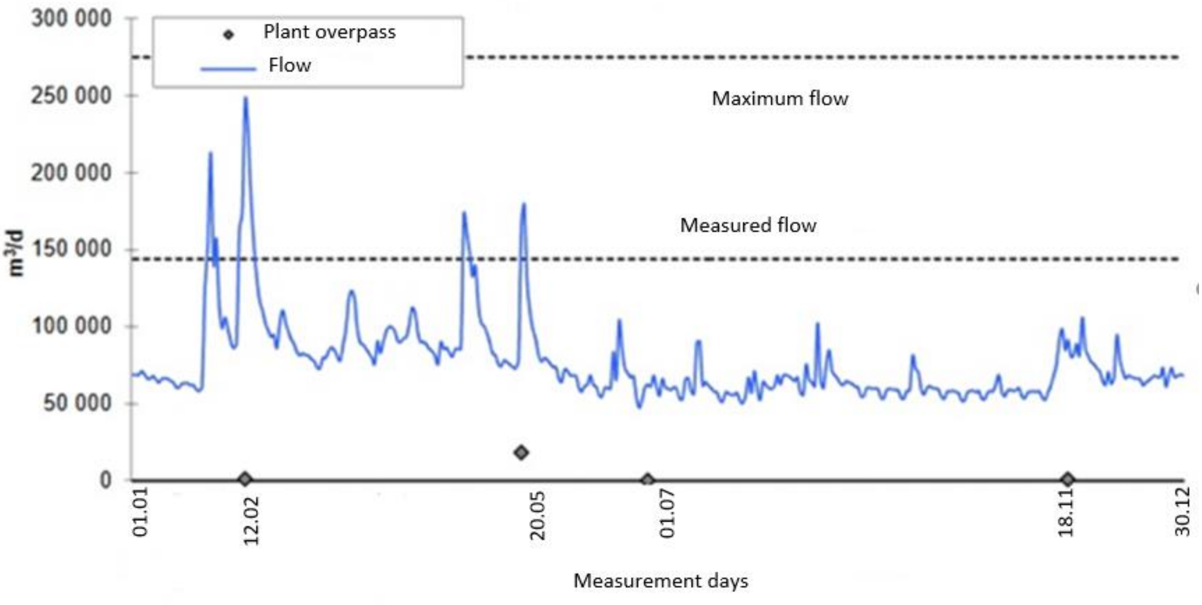


Figure 28: The effluent to the Turku WWTP. (Lounas-Suomen vesi- ja ympäristötutkimus Oy, 2018)

The Table 16, represents the concentration and the weight of the BOD, and other chemicals effluent of the Turku WWTP. From the graph we can see that all the concentrations exceed the normal concentration between 50 and 200%. Only the ammonia concentrations are less than the normal.

Table 16: chemical influent concentration (mg/L) of the Turku WWTP. (Lounas-Suomen vesi- ja ympäristötutkimus Oy, 2018)

Concentration (mg/L)						
	I/2016	II/2016	III/2016	IV/2016	year/2016	Measurement mg/L
BOD	260	280	340	340	410	180
COD/	590	660	830	960	740	430
phosphor	7,1	7,2	9,6	11	8,4	6,3
Nitrogen	55	60	75	82	66	35
Noh ammonia	41	46	58	62	51	
Total sludge	290	320	400	410	350	275

the Table 17 represents the Turku WWTP chemicals load. as the 4 Fourth quarter of 2016, all the concentrations are higher than the other 3 third quarters. the same is as for the concentration as for the flows.

Table 17: Flow and concentration for the year 2016 (Suunnittelukeskus Oy, 30.11.2005).

	Concentration (mg/l)					Measurement
	I/2016	II/2016	III/2016	IV/2016	2016	mg/l
BOD_{TATU}	260	280	340	410	310	180
COD_{Cr}	590	660	830	960	740	430
Phosphors	7.1	7.2	9.6	11	8.4	6.3
Total Nitrogen	55	60	75	82	66	35
Ammonium	41	46	58	62	51	------
Total sludge	290	320	400	410	350	275

	Flow (Kg/d)					Measurement
	I/2016	II/2016	III/2016	IV/2016	2016	mg/l
BOD_{TATU}	25000	24000	21000	27000	24000	22000
COD_{Cr}	56000	56000	52000	63000	57000	52000
Phosphors	680	610	600	690	650	760
Total Nitrogen	5300	5100	4700	5400	5100	4200
Ammonium	3900	3900	3600	4100	390	------
Total sludge	28000	27000	25000	25000	27000	33000

	Concentration (mg/l)					Measurement
	I/2016	II/2016	III/2016	IV/2016	2016	mg/l
BOD_{TATU}	260	280	340	410	310	180
COD_{Cr}	590	660	830	960	740	430
Phosphors	7.1	7.2	9.6	11	8.4	6.3
Total Nitrogen	55	60	75	82	66	35
Ammonium	41	46	58	62	51	------
Total sludge	290	320	400	410	350	275

The Figure 29, shows the details of the WWTP simulation of this thesis. Also, chemicals added to wastewater treatment are shown.

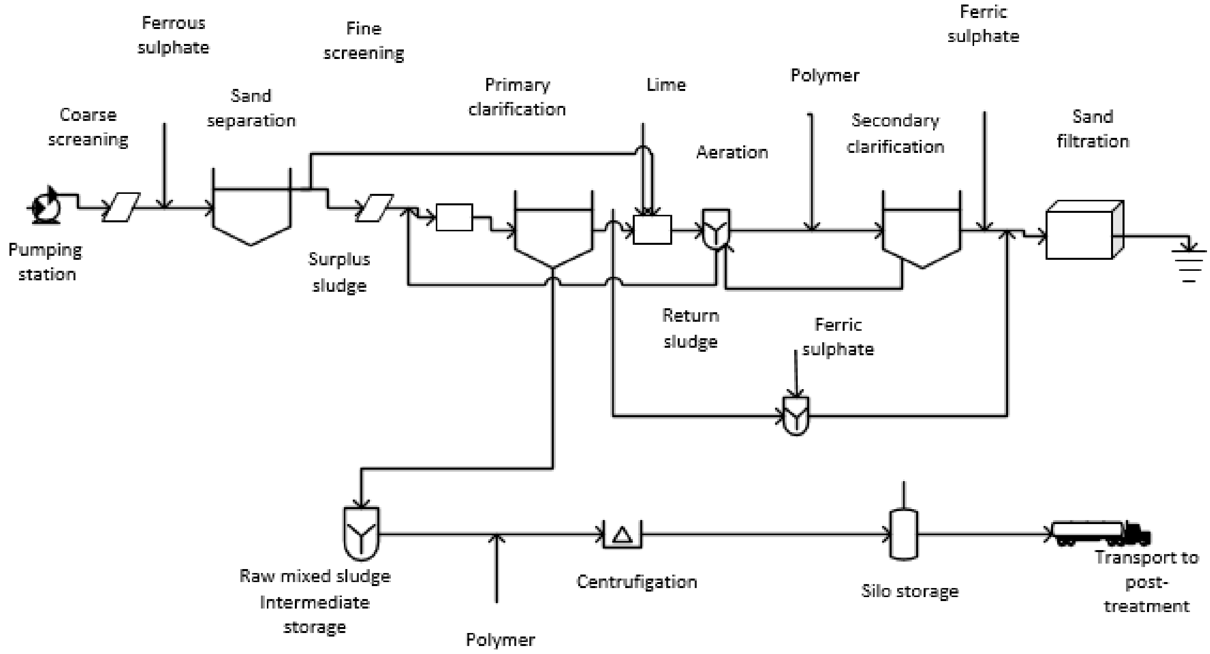


Figure 29: Turku wastewater treatment plant, adapted from company figure (Suunnittelukeskus Oy, 30.11.2005).

The Turku WWTP is situated in the south-west of Finland, with a capacity of an average of 120000 $m^3 d^{-1}$ and with a maximum biological processed flow rate of 173000 $m^3 d^{-1}$. Because of the restricted capacity, in time of ice melting or flooding, the WWTP needs an overpass of threated water. The WWTP contains a coarse separation, a sand separator, four (4) primary clarifiers, four (4) tanks for the aeration, four (4) secondary clarifiers and a series of sand filtration. For the by-pass water, there is a tank for chemical treatment by ferric sulphate. In case of extreme weather as ice melting or flood there is a by-pass from the primary clarifier directly to by-pass tank, then the flow goes to the sand filtration. for the overpass in peak hydraulic flow, Actiflo® treatment unit is used adding ferric sulphite.

the Actiflo® is process for WWTP proposed from VEOLIA company (Veolia, 2020). it is a micro sand ballasted clarification process, combining two (2) processes: Microsand floc formation and Microsand settling. in the case of Turku WWTP, ferric sulphite is added to the process.

The figure below shows the layout made for the simulation with overflow of the gravity thickener and the diffused aeration tank, directly to the tank of activated sludge model.

For the simulations, the average data collected from the influent of WWTP of Turku was used. From the Table 18 , we can see that the maximum hydraulic load is about 275 000 m3/d, the overload is treated by Actiflo®, the average is about 8000 m3/h. The data was collected form the official Turku WWTP. The data was in form of yearly reports.

Table 18: Average parameters of the Turku WWTP. (Suunnittelukeskus Oy, 30.11.2005)

Parameters	Value	Units
Maximum flow rate/day	275 000	m3/d
Maximum biologic processed flow rate	173 000	m3/h
MAXIMUM pre-treated flow	13 750	m3/h
Maximum biological primary treated	7700	m3/h
Maximum sand filtration flow rate	13750	m3/h
Maximum rejection flow rate treated by Actiflo®	8000	m3/h
BOD	180	mgL^{-1}
COD	430	mgL^{-1}
Phosphorus	6.3	mgL^{-1}
Total Nitrogen	35	mgL^{-1}
Ammonium	50	mgL^{-1}
Total sludge	275	mgL^{-1}

4.3. steady state software

Steady state wastewater treatment plant modelling program is a software developed by the university of Texas at Austin, at the department of civil engineering. the authors are Luis Abuto-garnica and Gerald E. Speitel Jr.

the software is very easy for use. with its helpful interface, the user can find easily the units needed in the simulations. apart the simulation results, it also gives the mathematical calculation for every step of wastewater treatment. the Figure 30 represents the interface units used in the process simulation.

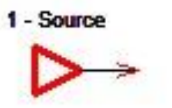
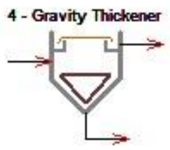
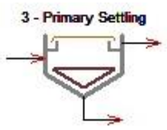
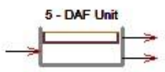
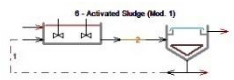
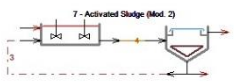
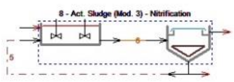
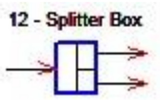
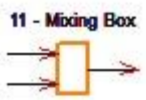
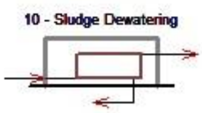
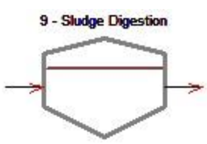
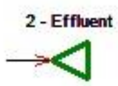
Unit	Explication
	source
	Gravity thickener
	Primary settler
	DAF-unit
	ASM1
	ASM2
	ASM3
	Splitter box
	Mixing box
	Sludge dewatering
	Sludge digestion
	Effluent

Figure 30: Steadystate software units.

4.4 simulation

The data was collected from the Turku WWTP annual report of 2019., the one-year flow rates are represented in the Figure **31**.

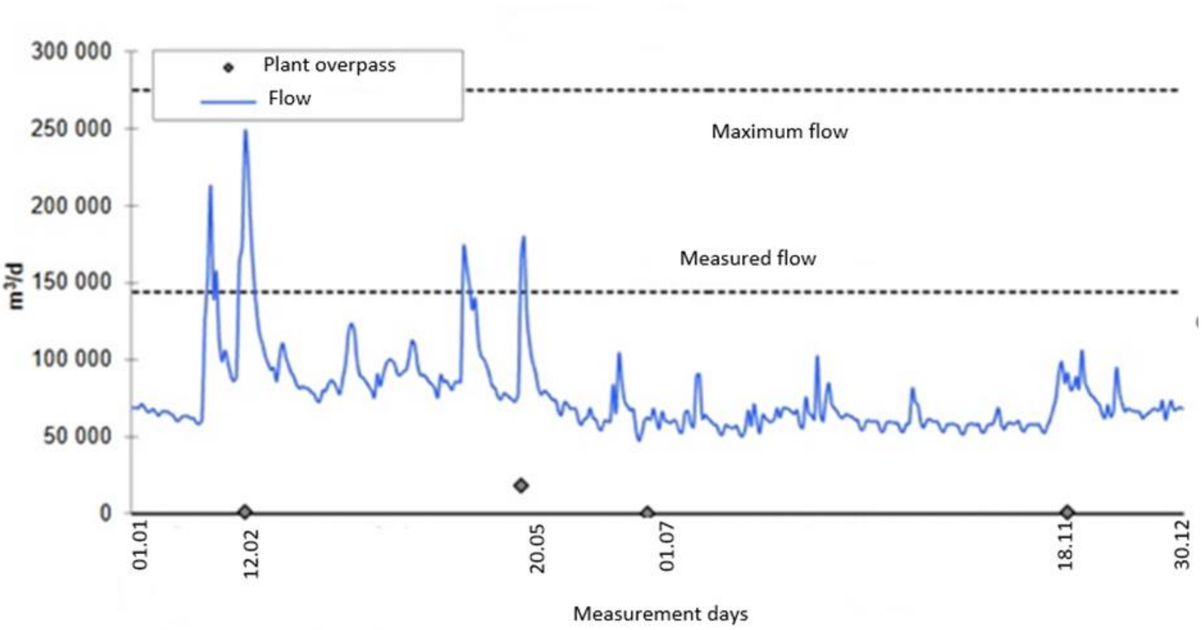


Figure 31: Turku WWTP processed flow. (Suunnittelukeskus Oy, 30.11.2005)

The Table 19 represents the average of flow rate and the treated flow rates of the Turku´s WWTP, as seen in the table below, the average flows rates do not changes a lot by years. for the year 2014 the average flow rate was 81000 m^3/d, for the year 2019 it was a maximum of 93300 m^3/d.

Table 19: Turku WWTP flowrates, 2014-2019. (Suunnittelukeskus Oy, 30.11.2005)

year	average flow rates m^3/d	maximum flow rate m^3/d	treated average flow m^3/d	treated maximum flow m^3/d
2014	81000	305000	81500	303300
2015	88400	264600	88300	264600
2016	77000	247900	76900	247000
2017	84100	277571	84000	277571
2018	74100	214730	74100	214730
2019	93300	281534	93280	281942

The chemicals loads are monitored, the influent organic compositions is represented in Table 20 below, it shows the 2016-year concentrations of effluent organic composition.

Table 20: Turku WWTP concentrations of effluent organic composition of the 2016 year (Suunnittelukeskus Oy, 30.11.2005)

	Concentration (mg/l)				Measurement*	
	I/2016	II/2016	III/2016	IV/2016	2016	mg/l
BOD_{TATU}	260	280	340	410	310	180
COD_{Cr}	590	660	830	960	740	430
Phosphors	7.1	7.2	9.6	11	8.4	6.3
Total Nitrogen	55	60	75	82	66	35
Ammonium	41	46	58	62	51	------
Total sludge	290	320	400	410	350	275

The simulation was hold with the steadystate® software. The Figure **32** represents the Plant layout adapted from steadystate software

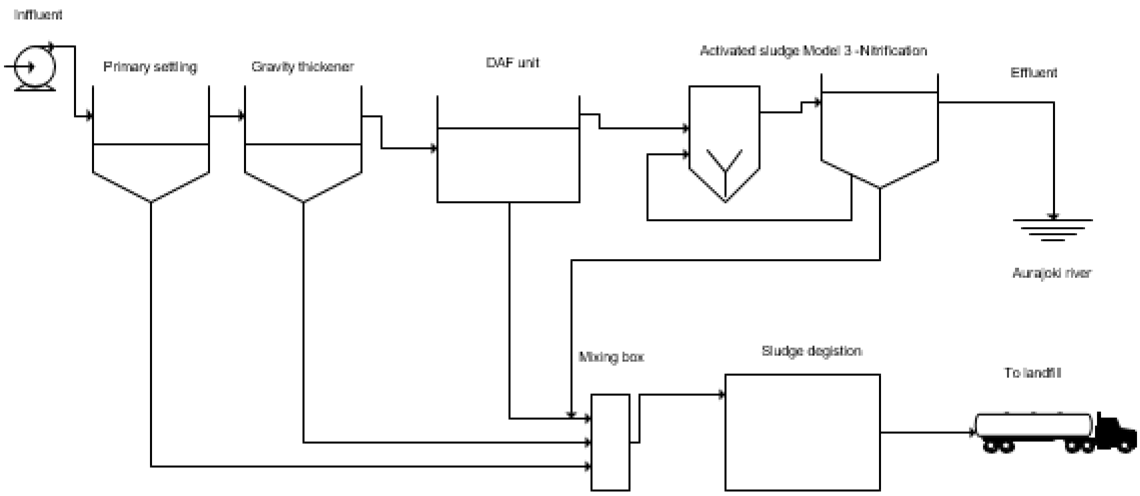


Figure 32: Turku WWTP adapted from steadystate.

There will be two (2) layouts, one without overflow, the second one with overflows over 500 L/s with overpass.

The layout contains:

- a source
- mixing boxes
- primary settling
- gravity thickener
- activated sludge model
- sludge digester
- sludge dewatering
- diffusate air flotation
- Spittle box for the wastewater overflow.
- effluents, one for sludge digester and one for water from activated sludge models

For the simulation, the chemical compound in the source stays the same, only waterflow is changing if the hydraulic load is over the capacity of the WWTP.

The basin shape was taken as circular, the measurement was: unit depth equal to 4m, the unit volume was equal to 4344 m^3. The aeration tank volume was 2914 m^3, the tank aera was 485 m^2. The clarifier volume was 6055 m^3, the surface aera was 1730 m^2. The hydraulic retention time was 3,36 hours.

For the simulation with overpass, as shown in Figure **33**, in case of hydraulic load overpassing the capacity of the WWTP, the flow was divided in to two flows. 50% of the first loads goes through normally designed treatment. The second 50% flow goes from the primary settling to isolated gravity thickener, then to a sand filter then to the effluent.

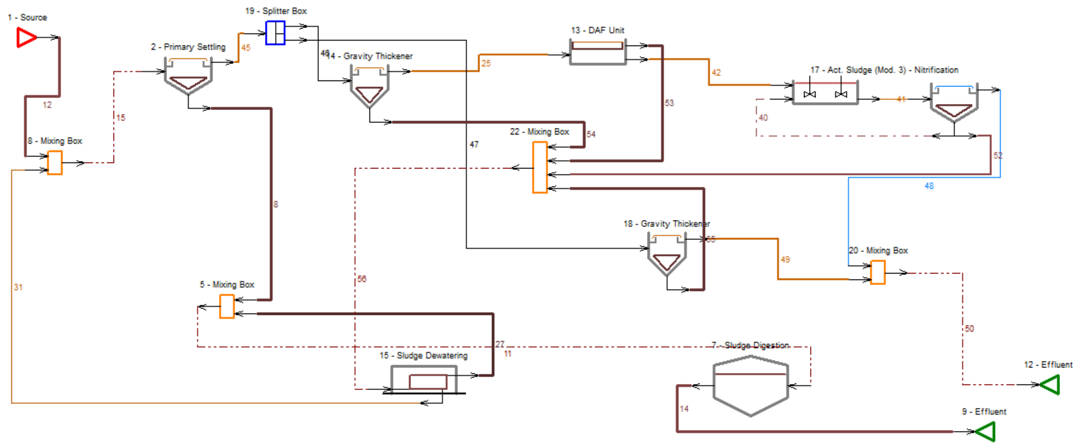


Figure 33: Turku WWTP unit process with overpass (steadystate software).

The Figure **34**Error! Reference source not found., represents the Turku WWTP site, it is totally built underground. in the city centre, Turku. Also, it is close to the Aura River, to which the treated water is rejected.

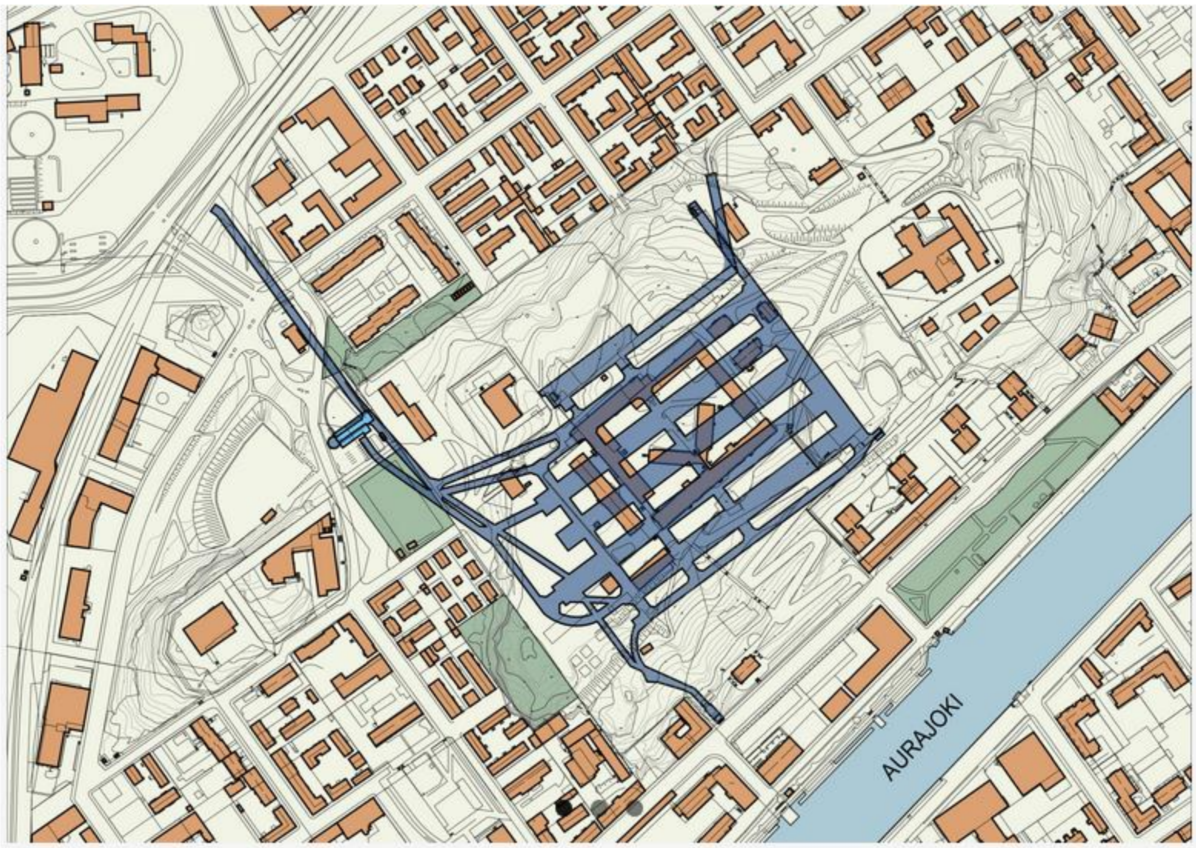


Figure 34:Turku´s WWTP site. (Suunnittelukeskus Oy, 30.11.2005)

4.5. Results.

The influent characteristics was calculated from the Turku´s WWTP data. The concentrations were calculated from the first data concentration which corresponds to the average flow and chemical concentrations of Turku´s WWTP. The Table **21** represents the data used for the simulation.

Table 21: Data used for the simulations.

Flow L/s	TBOD	TSS	TKN	NH3-N	SBOD % of TBOD	VSS % of TSS
125 L/s	880	880	160	98	30	80
250 L/s	440	440	80	48	30	80
500 L/s	220	220	40	25	30	80
600 L/s	183.3333	183.3333	33.33333	20.83333	30	80
700 L/s	157.1429	157.1429	28.57143	14.88095	30	80
800 L/s	137.5	137.5	25	15.625	30	80
900 L/s	122.2222	122.2222	22.22222	13.88889	30	80
1000 L/s	110	110	20	12	30	80

The Table22 , represent the chemicals concentrations of the effluent with different simulations. the simulation was started with 125L/s, then 250, 500, 600, 700, 800, 900 and 1000L/S. the concentrations remains constant, thus because of the flow rate from residentials wastewater is the same, the changes are coming only from stormwater. or from flooding flow rate.

Table22: Effluent characteristics for the Turku WWTP simulations.

Flow L/s	Qe	TBODe	SBODe	TSSe	VSSe	TKNe	NH3e
125	124.37	20	10.20	20	19.6	5	5
250	249.66	20	10.20	20	19.76	5	5
500	499.39	20	10.26	20	19.47	5	5
600	599.43	41.41	32.65	13.86	12.8	13.18	12.82
700	699.38	36.92	28.75	13.69	12.59	10.23	9.94
800	799.44	33.56	25.8	12.89	11.97	10.51	10.31
900	899.44	30.94	23.53	12.57	11.67	9.62	9.45
1000	999.44	28.84	21.7	12.20	11.41	8.70	8.5

The data used to compare the Turku WWTP and the Simulation made by steadystate software was BOD, TSS, TKN and Ammonia. The Table 23 represents the concentration used in the simulation with overpass. We can notice that all concentration of the effluent is below the plant´s recommendation which was 80% removal. The first two rows show a normal simulation. Starting from 500L/s, the simulations were done with overpass which means 50% of the flows goes through normal process, the other 50% of the flows goes from the first clarifier to a gravity thickener without passing through the ASM process.

Table 23. Results for Turku WWTP simulations with overpass and different Hydraulic loads.

Flow L/s	BOD	TSS	TKN	Ammonia
500	47.6	14.5	15.3	15
600	41.3	13.7	13.2	12.9
700	36.8	13.2	10.2	9.89
800	33.4	12.8	10.2	9.9
900	29.9	12.5	10.4	10.3
1000	28.8	12.2	8.7	8.5

The Table 24 , represents the concentration of the chemicals pollutants in the effluent processed by the Turku´s WWTP. comparing the simulation calculation to this data below, we can notice that the simulation fit with the Turku´s WWTP.

Table 24: Chemical's pollutants in the effluent processed from Turku WWTP. adapted from: (Suunnittelukeskus Oy, 30.11.2005)

	concentration mg/L				
	I/2019	II/2019	III/2019	IV/2019	year average
CODCr	26	23	22	30	27
BOD7ATU	3,6	1,6	2,9	6,2	4
Phosphor	0,086	0,088	0,13	0,13	0,11
Total Nitrogen	8,6	7,3	7,7	7,8	7,9
Ammonia	1,6	0,22	0,83	2,4	1,4
Total sludge	2,1	0,68	1,4	4,9	2,6

From the Table **25**, we can see that concentration of BOD and TSS are higher than the Turku WWTP concentration respectively 5 and 7 times. Only the TKN concentration is less than the Turku WWTP.

ammonia concentration was higher 4.5 time than the concentration of the Turku WWTP effluent. This simulation was done with normal average from data of influent of Turku WWTP.

Table 25. Simulation number one 125L/s without overpass compared to the data from Turku WWTP.

	Organic matter mg/L		Nitrogen mg/L	
	BOD	TSS	TKN	Ammonia
Simulation N 1 without overpass 125L/s	20	20	5	5
data from Turku WWTP effluent	4	2.6	7.8	1.4

The simulation with over pass (1000 L/S), the Table **26** shows a big difference compared to data from Turku WWTP effluent. The simulated BOD and TSS concentrations are 6 and 8 time higher than Turku WWTP effluent concentrations. The Nitrogen concentration in form of TKN is higher about 15% than the Turku WWTP effluent average, the Ammonia concentration was higher 6 time than the concentration from the Turku WWTP.

Table 26: Data from simulation with overpass 1000L/s, compared to Turku WWTP data.

	Organic matter mg/L		Nitrogen	
	BOD	TSS	TKN	Ammonia
Simulation 2, 1000 L/s with over pass	23.5	16.9	8.7	8.5
Turku WWTP effluent data average	4	2.6	7.8	1.4

The Table **27** represents the overpass simulations, the results are shown in table below. The flow rate was taken as 500, 600, 700, 800, 900 and 1000 L/s, the overpass was 20%.

As we can see, the organic matter and the nitrogen concentrations are higher than the concentrations and the one of the simulations number 1. This was due to the overpass of 50% which does not go the Diffusion air filtration and ASM units.

Table 27: Simulations comparison to the Turku WWTP effluent data.

	Organic matter mg/L		Nitrogen mg/L	
	BOD	TSS	TKN	Ammonia
Simulation 1 without overpass 125 L/s	20	20	5	5
Simulation 2 with overpass 500 L/s	47.6	14.5	15.3	15
Simulation 3 with overpass 600 L/s	41.3	13.7	13.2	12.9
Simulation 4 with overpass 700L/s	36.8	13.2	10.2	9.89
Simulation 5 with overpass 800L/s	33.4	12.8	10.2	9.9
Simulation 6 with overpass 900L/s	29.9	12.5	10.4	10.3
Simulation 7 with overpass 1000L/s	28.8	12.5	8.7	10.3
Data from Turku WWTP effluent	4	2.6	7.8	1.4

The Figure **35** shows the relation between the concentrations and flowrates. the concentration presented and used in the simulations are BOD, TSS, TKN and NH3e.

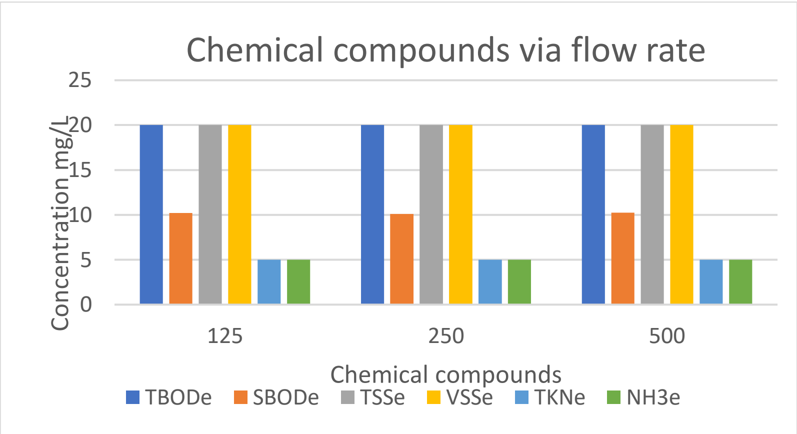


Figure 35: Concentration vs flow rates: Concentration VS flow rate

The Figure **36**Error! Reference source not found. shows the effluent concentration with an overpass simulation. the flow rates used are: 600, 700, 800, 900 and 1000 L/s.

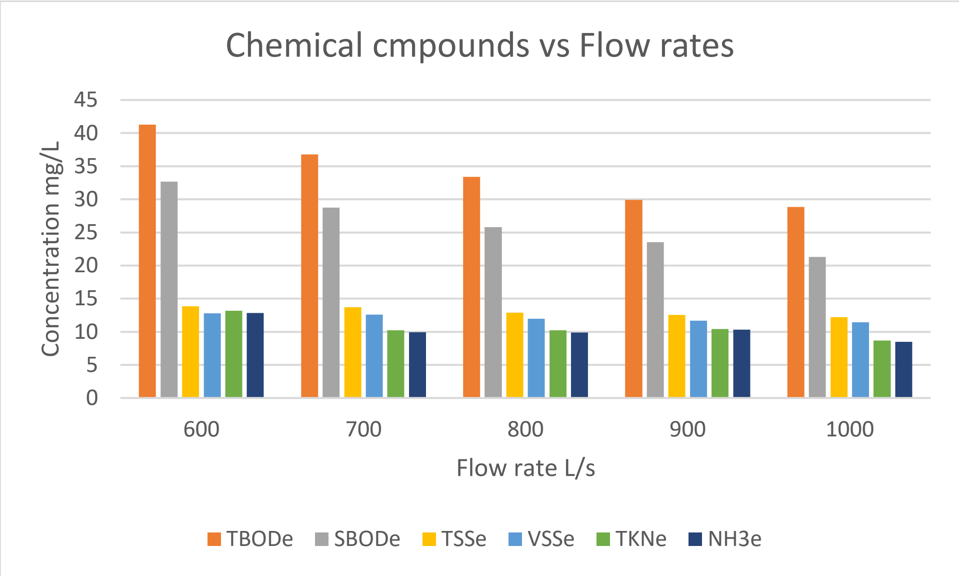


Figure 36: Concentration vs flow rate (in case of by-pass)

5. Discussion

The target of this thesis was to simulate and evaluate the work of Turku´s WWTP in different situation. Especially, the simulations were done with overflow situations as flood. The calculations and simulation allowed to find problems and to propose solutions or remediations for the WWTP unit and works. The simulation was done with the SteadyState software. The major factor for the work of a WWTP is Nitrogen and Phosphorus removal, those 2 chemicals compounds cause the most injuries to the water sources as lakes, rivers and seas.

The nutrient´s presence in water allows the growth of algae which reduce the oxygen presence and concentration. The water sources inhabitants as fish and shells growth depends on water contamination, the less water is contaminated is the les their growth is. Furthermore, the birds depending on fish in their food, are present in places where the fish and shells are less contaminated, and where the fish population is enough for them.

In this case was also simulated the overflow loads, and the reject water constitution. The reject water is dumped in this to the Eurajoki. The quality of the reject water depends dramatically on the effectiveness of the WWTP process and capacity.

The parameters used in the simulation are the BOD, TSS, TKN and Ammonia concentrations. The result of the simulation can be seen in the Table 16, where Flow rate, concentrations of TBOD, SBOD, TTS, VSS, TKN and NH_{3e} were collected. From flow of 125 to 500 L/s, the concentration of TBOD, BOD, TSS, TKN, and NY3e, remains very stable. Starting at 600 to 1000L/s flow rate, the concentrations increase dramatically.

The simulation parameters and the data from the Turku WWTP, were difficult for comparison. This because of the data collected from Turku WWTP is an average, which does not prove and shows the real time data of influent and effluent concentration.

All concentration parameters grow dramatically in the fourth quartal, its two times higher than the concentration in the first quartal. The BOD, COD, Phosphorus, Total Nitrogen Ammonium and total sludge concentrations grow from the first quartal and see it peaks.

The concentration high amount is due to the overpass of the loads when there is flood or snow thawing. The flows when passed higher than 500L/s it divided to 2 parts, 50 % of the flows passes the normal unit operation processes. The second 50% of the flow passes after the primary settling directly to the gravity thickener then to the sand filter, thus it does not pass through the DAF unit, through the Activated sludge model. That is the explanation of why the Ammonia and TKN concentrations are very high in the effluent,

The use of a sand filter in this case reduces dramatically the concentration of nutrients before rejecting water to the effluent. Also, the use and recycling of nutrients from wastewater would be the best solution for water quality. The recycling can be expensive and makes the whole process of wastewater treatment highly expensive.

As seen from the simulation results the overflow coming from stormwater and runoff is higher contaminated than residential wastewater and has a big influence on the effluent's characteristics. The effluent concentration (in case of by-pass) is in times higher than the concentration limit with normal flow rates. The high flow coming from flood, melting snow or storm water reduce the capacity of the WWTP units. It is recommended to construct different system for collecting stormwater, especially the runoff. These systems can be from residential houses stormwater and runoff collecting and filtrating on-land, to roads system collectors and filters. The sewage system of runoff and stormwater collectors should not be connected to the WWTP facilities.

From simulation we can see that the TBOD concentration is between 3 and 4 time higher in the case of by-pass. The SBOD concentration remain the same or is 1,5 time higher in by-pass, than the normal process without by-pass. The concentration of TKN and NH^{3e}, are 3 time higher in the by-pass simulation, than the one without by-pass.

The data collected from Turku WWTP effluent data and the simulations data done with steadystate software. The organic matter concentration (BOD and TSS) is between 5 and time 15 time higher than the concentration in the Turku WWTP. Also, Nitrogen concentration (TKN and Ammonia) is higher between 1 and 10 times compared to the data from the Turku WWTP.

It can be decided that in case of extreme weather as snow thawing or flood, the WWTP work can not fit the legislation norms in term of concentration of organic matter or Nitrogen.

One solution proposed can be the collection of storm water in some channels or lagoons, to minimize the load on the WWTP. Later collected water can be driven to WWTP for treatments, this will reduce the effluents high concentration of harmful compounds, as Nitrogen, BOD, COD and Phosphorus.

For future studies. It will performant to make an in-situs study with an online laboratory research. Software like SteadyState doe does not allow to simulate and modulate the Phosphorus for the modelling of activated sludge plants. The whole data can be collected by AI, the software allows automatically control for all pumps and unit's operation.

The chemical used in WWTP as: Lime, ferric sulphate, polymers, ferrous sulphate can be added automatically, which will reduce time sources and resources consuming. Also, AI can collect data from weather forecasts centres, to predict floods or snow thawing. Also, water characteristics can be check online which will perform the work of WWTP.

AI can control without Humans the efficiency of different unit of the processes. It can help the operators to make decisions faster.

The large data of WWTP can be monitored by Artificial intelligence, thanks to the digitalization, this is due to the large component used, units of operation, pumps, chemicals.

Bibliography

Iowa Homeland Security and Emergency Management, 2008. *https://eda.gov/success-stories/disaster/stories/ia-city-water-supply.htm.* [Online].

Alex, J. J. U. B. U., 1999. On-line simulation of wastewater treatment plants. *IFAC Proceedings volumes,* 32(2), pp. 5794-5799.

Anon., 2020. *https://www.veoliawatertechnologies.com/en/technologies/actiflo.* [Online] [Accessed 2020].

Babko, R. S.-C. J. D. Y. D. S. K.-B. M. Ł. G., 2019. Effect of Stormwater System on the Receiver. *Journal of ecological engineering,* 20(6), pp. 52-59.

Baeten, J. B. D. S. O. v. L. M. V. E., 2019. Modelling anaerobic, aerobic and partial nitritation-anammoxgranular sludge reactors. *Water Research,* Volume 149, pp. 322-341.

Bournazou, C. M. A.-G. H. W. G. K. C., 2010. Model reduction of the ASM3 extended for two-step nitrification. *International federation of automatic control,* 43(6), pp. 60-65.

Coen, P. B. P. B. M., 1998. Model-based characterisation of hydraulic, kinetic and influent properties of an industrial WWTP. *Water Science and Technology,* 37(12), pp. 317-326.

Coohill, T. P. S. J.-L., 2003. Bacerial inactivation by solar ultraviolet radiation compared with sensitivity to 254 nm radiation. *photochemistry and photobiology,* 85(5).

David, R., Vasel, J.-L. & Wouwer, A. V., 2009. Settler dynamic modeling and MATLAB simulation of the activated sludge process. *Chemical Engineering Journal,* 146(2), pp. 174-183.

Eckenfelder, W., 1980. *Principles of water quality management..* Boston: CBI Publishing Company Inc, Boston.

Elawwad, A. M. M. A.-z. M. H. A., 2019. Plant-wide modeling and optimization of a large-scale WWTP using BioWin's ASDM model. *Journal of Water Process Engineering.*

EPA; United States Environmental Protection Agency., 2020. *https://www.epa.gov/ceam/water-quality-analysis-simulation-program-wasp.* [Online]
Available at: https://www.epa.gov/ceam/water-quality-analysis-simulation-program-wasp
[Accessed February 2020].

Fujioka, R. N. O., 1982. Effect of sunlight on enumartion of indicator bacteria under field conditions. *Applied and environmental microbiology,* 44(2), pp. 395-401.

Gernaey, K. v. L. H. L. J., 2004. Activated sludge wastewater treatment plant modelling andsimulation: state of the art. *Environmental Modelling & Software,* Volume 19, pp. 763-783.

Goel, R. M. A. M., 2013. *Comprehensive Water Quality and Purification.* s.l.:Elsevier Inc.

Grau, P. P. M. S. S. E. C. P. G. W. G. M. H. J. K., 1983. RECOMMENDED NOTATION FOR USE IN THE DESCRIPTION OF BIOLOGICAL WASTEWATER TREATMENT PROCESS. *Applied chemistry,* Volume 6, pp. 1035-1040.

Guo, L. T. S. L. J. M. S. D. E. E. V. P. A., 2019. Conceptualizing the sewage collection system for integrated sewer-WWTP modelling and optimization. *Journal of Hydrology,* Volume 573, pp. 710-716.

Henze, M. et al., 1987. *Activated sludge model N 1,* London: IAWPRC.

Henze, M., Gujer, G., Mino, T. & van Loosdrecht, M., 2002. ACTIVATED SLUDGE MODELS ASM1, ASM2d, and ASM3. *IWA.*

Hilliges, R. E. M. T. A. ,. B. E. M. T., 2017. Characterization of road runoff with regard to seasonal variations, particle size distribution and the correlation of fine particles and pollutants. *Water scicence technology,* 75(5), pp. 1169-1176.

Holt, E. K. H. K. J. S. N. W. L., 2018. *Filtration systems for stormwater quantity and quality management. Guideline for Finnish implementation,* Espoo: VTT technical research centre of finland ltd.

hydromantis, 2020. *https://www.hydromantis.com/GPSX-models.html#standard.* [Online]
Available at: https://www.hydromantis.com/GPSX-models.html#standard
[Accessed 2020].

Iacopozzi, I. I. V. M.-L. S. ,. G. E., 2007. A modified Activated Sludge Model No. 3 (ASM3) withtwo-step nitrificationedenitrification. *Environmental Modelling & Software,* Volume 22, pp. 847-861.

Jeppsson, U. B. A. H. D. J. H. K. E., 2005. *The URWARE WastewaterTreatment Plant Models,* Gothenburg, Sweden, : CHALMERS UNIVERSITY OF TECHNOLOGY.

Jouanneau, S. L. R. M. D. A. B. V. P. Y. P. A. L. M. S. B. B. G. T., 2013. Methods for assessing biochemical oxygen demand (BOD): A review. *water research,* Volume 49, pp. 62-82.

Juuti, P. R. R., 2010. Jätevedenpuhdistuksen ja viemäröinnin vaiheita Helsingissä. In: *Metropoli ja meri - 100 vuotta jätevedenpuhdistusta Helsingissä.* s.l.:HSY & TAMPUB, pp. 36-89.

Kersalo, J. P. P., 2009. *SUOMEN MAAKUNTIEN ILMASTO,* Helsinki: Ilmatieteen laitos.

Laizāns, A. Š. A., 2012. *Analytical model and simulation of oxygen solubility in wastewater.* Jelgava , Latvia University of Agriculture.

laplandsafaris.com, 2020. *https://www.laplandsafaris.com/en/tips/hours-of-daylight-in-lapland.* [Online]
Available at: https://www.laplandsafaris.com/en/tips/hours-of-daylight-in-lapland

Lindell, M. .. G. H. W. T. L., 1996. Effect of sunlight on bacterial growth in lakes of different humic conent. *Aquatic microbial ecology,* Volume 11, pp. 135-141.

Lounas-Suomen vesi- ja ympäristötutkimus Oy, 2018. *KAKOLANMÄEN JÄTEVEDENPUHDISTAMOE-PRTR ASETUKSEN MUKAISET PÄÄSTÖT JAVESIYMPÄRISTÖLLE VAARALLISET JA HAITALLISET AINEET,* s.l.: Lounas-Suomen vesi- ja ympäristötutkimus Oy.

Metcalf and Eddy, 2003. *Wastewater engineering. Treatment and ruse.* fourth edition ed. s.l.:s.n.

Mike powerd by dhi, 2020. *https://www.mikepoweredbydhi.com/products/west.* [Online]
Available at: https://www.mikepoweredbydhi.com/products/west
[Accessed February 2020].

Milina, J. S. S. L. J. K. A. N. O. E. A. A. J. S. W., 1999. Imrpoved interception of combined sewage in the Trondheim-Hovringen wastewater system. *Water sciences technology,* 39(2), pp. 159-168.

Ministry of Agriculture and Forestry, F., 2010. *Flood Risk Management Act (620/2010),* s.l.: Ministry of Agriculture and Forestry, Finland.

Ministry of Agriculture and forestry, F., 2015. *Water Services Act (119/2001),* s.l.: Ministry of Agriculture and forestry, Finland.

NRC, N. R. C., 1993. KEY ISSUES RELATING TO WASTEWATER AND STORMWATER MANAGEMENT. In: *Managing Wastewater in Coastal Urban Areas..* Washington, DC, USA: The National Academies Press., pp. 55-56.

Song, X. M. M. &. H. P., 2011. Enzymatic synthesis of DNA employing pyrophosphate-linked dinucleotide substrates. *Journal of Systems Chemistry .*

Stein, L., 2015. Microbiology: Cyanate fuels the nitrogen cycle. *Nature.*

Suunnittelukeskus Oy, 30.11.2005. *Kakolanmäen jätevedenpuhdistamo, toteutussuunnittelu, prosessisuunnitelma, vuoden 2030 tilanne,* s.l.: s.n.

TRAFIKVERKET, 2018. *Reducing Highway Runoff Pollution, sustainable design and maintenance of stormwater treatment facilities,* s.l.: TRafikverket.

USEPA, 2001. *Our built and natural environments,* Washington: development, comunity and environment division.

USGS, 2020. *https://www.usgs.gov/special-topic/water-science-school/science/biological-oxygen-demand-bod-and-water?qt-science_center_objects=0#qt-science_center_objects.* [Online] [Accessed 2020].

Vähäaho, I., 2014. Underground space planning in Helsinki. *Journal of Rock Mechanics and Geotechnical Engineering,* 6(5), pp. 387-398.

Veolia, 2020. *https://www.hydromantis.com/GPSX-models.html#standard.* [Online].

Welker, A. L. U. K. K. S. ,. T. G., 1999. Effects of integrated stormwater management strategies on the combined sewer system and the wastewater treatment plant-river system. *Water sciences technology,* 39(2), pp. 151-157.

www.hydromantis.com/, n.d. *https://www.hydromantis.com/.* [Online].

Yang, S. S. P. J. G. Y. W. R. N. Z. Q., 2017. Biological phosphorus removal in an extended ASM2 model: Roles of extracellular polymeric substances and kinetic modeling. *Bioresource technology,* Volume 232, pp. 412-416.

Zhou, M. G. J. Y. C. P. W., 2013. Simulation of the performance of aerobic granular sludge SBR using modified ASM3 model. *Bioresource Technology,* Volume 127, pp. 473-481.