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# Study of Water Quality in Urban Streams: Mätäjoki and Haaganpuro

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<p>Mätäjoki and Haaganpuro have been important urban streams in Helsinki in terms of their ecological and recreational values. These streams have been well known as a spawning place for trout. They have been home to many flora and fauna and carry a significance importance in the surrounding ecosystem.</p> <p>The main aim of this thesis was to study the current condition of water quality in these streams in terms of physical and chemical parameters that include temperature, pH, electrical conductivity, dissolved oxygen, turbidity, total iron, total phosphorus and total nitrogen.</p> <p>First, literature review was done to know about parameters and their effects on water quality. Parameters such as temperature, pH, electrical conductivity, dissolved oxygen were determined onsite and other parameters such as nutrients, iron and turbidity were determined in the Environmental Engineering Laboratory of Metropolia University of Applied Sciences. Five water samples of each streams were taken from five different locations of streams for the chemical analysis.</p> <p>The result shows that the overall water quality of Mätäjoki and Haaganpuro is good. Concentration of dissolved oxygen was found to be very low in the first two sampling sites of Mätäjoki. Average concentration of total phosphorus in Mätäjoki is more than it was in 1995-1996 and 2004. Haaganpuro has better water quality than Mätäjoki.</p>	
Keywords	urban streams, Mätäjoki, Haaganpuro, water quality monitoring, water quality parameters

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I am fully responsible for any kind of errors and any grammatical and spelling mistakes in my thesis report. Finally, I want to dedicate this thesis to my mother who believed in me and always supported and encouraged me in every step of my life.

June 2017,

Shree Ram Bhusal

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## List of Abbreviations

AA	Atomic Absorption
AAS	Atomic Absorption Spectroscopy
AES	Atomic Emission Spectroscopy
Aq.	Aqueous
ATP	Adenosine Tri-Phosphate
CCD	Charge Coupled Device
DNA	Deoxyribonucleic Acid
DO	Dissolved Oxygen
EU	European Union
FTU	Formazin Turbidity Units
g	gas
ICP-AES	Induced Couple Plasma Atomic Emission Spectroscopy
K	Kelvin
l	liquid
MP-AES	Microwave Plasma Atomic Emission Spectroscopy
nm	nanometer
NTU	Nephelometric Turbidity Units
pH	Potential Hydrogen
pm	Picometer
ppb	Parts per billion
ppm	Parts per million
S	Siemens
TDS	Total Dissolved Solids
UV	Ultraviolet
vs	Versus
WHO	World Health Organization



## List of Symbols

H <sub>2</sub> O	Water
H <sub>2</sub> SO <sub>4</sub>	Sulfuric acid
CO <sub>2</sub>	Carbon dioxide
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	Glucose
Fe	Iron
K <sub>w</sub>	Ionization constant of water
l/s	Liter per second
SO <sub>2</sub>	Sulfur dioxide
S/cm	Siemens per centimeter
S/m	Siemens per meter
dS/cm	deci Siemens per centimeter
μS/cm	micro Siemens per centimeter
mg/l	milligram per liter
μg/l	microgram per liter
NH <sub>3</sub>	Ammonia
NH <sub>4</sub> <sup>+</sup>	Ammonium ion
NO	Nitrogen Oxide
NO <sub>2</sub> <sup>-</sup>	Nitrite ion
NO <sub>3</sub> <sup>-</sup>	Nitrate ion
Fe(OH) <sub>2</sub> <sup>+</sup>	Ferrous Hydroxide
N	Nitrogen
P	Phosphorus
PO <sub>4</sub> <sup>3-</sup>	Ortho-phosphate
HPO <sub>4</sub> <sup>2-</sup>	Hydrogen Phosphate
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	Dihydrogen Phosphate

# 1 INTRODUCTION

Urban streams are a natural component of hydrological cycle that play a significant role in urban environment and community. Good ecological status of urban streams increases biodiversity and act as a recreational area for the local community. Testing of water quality of urban streams has been one of the important part of monitoring the environment. Poor water quality not only affects the aquatic life but also affects the ecosystem of surrounding. Monitoring of water quality of urban streams is necessary so that the researchers can predict and learn from the environment naturally and can determine the human impact on an ecosystem. [1]

There are more than 25 urban streams in Helsinki. Mätäjoki and Haaganpuro have been important streams in Helsinki in terms of their ecological and recreational values. They flow through forests, parks and residential areas. These streams are well known for sea trout and their ability to provide spawning ground for this fish species.

## 1.1 Mätäjoki

Mätäjoki is considered as the second largest water flow in Helsinki after the Vantaa river. It is known to be the former riverbed of Vantaa river. It flows from Louhela and Kaivoksela, Vantaa from where it flows to the south part of Helsinki via Malminkartano and Kannelmäki park areas, curves to the west Pitäjänmäki and finally reaches Laajalahti in the Gulf of Finland through the Iso-Huopalahti area in Helsinki. [2]

Mätäjoki has a catchment area of 24 km<sup>2</sup> where about 72000 people live in that area. It has a large catchment area because Mätäjoki is sensitive to rain that makes it flooded to overflowing. The length of main channel is about 9 km with the average flow of 170 l/s. The water quality of Mätäjoki has been reasonably good. Mätäjoki is rich in scrubby vegetation due to which it has been home to abundant bird lives. For example, nightingales are mostly found here, and water birds such as tufted ducks, golden eyed ducks and aspen witch birds are abundant. Mätäjoki has also been home to water voles. [3]

In 1995-1996, Mätäjoki was found to be polytrophic in terms of nutrient level. Nitrogen and phosphorous transportation amount was about 330.8 kg/ km<sup>2</sup> and 13.4 kg/km<sup>2</sup> respectively. The hygienic quality of Mätäjoki was passable during that period. The quality of water was much better since mid-1970s, and it was passable in terms of its general grading. [4] Figure 1 shows a photo of Mätäjoki stream near Kannelmäki.



*Figure 1. Mätäjoki stream*

## 1.2 Haaganpuro

Haaganpuro is the new name of Mätäpuro given to the stream in 1969. It was changed to Haaganpuro in 2011. The catchment area of Haaganpuro is approximately 10.7 km<sup>2</sup>. The main channel of Haaganpuro originates in Maununneva from where it flows to the south-western part to Maunulan Uurnalehto through Pakila and Pirkkola. Again, from Maunulan Uurnalehto it flows to southern part through Central Park. In Kivihaantie, the stream is pipelined below Hämeenlinnanväylä which again flows through Kauppalanpuisto and finally ends in Pikku Huopalahti. The length of main stream is estimated to be 11.6 km of which below 25% is pipelined. The average flow of Haaganpuro is about 101 l/s. [5] Figure 2 shows a photo of the Haaganpuro stream near Kauppalanpuisto.





*Figure 2. Haaganpuro stream*

Haaganpuro has been known for endangered brown trout, but due to the urbanization, trout stocks collapsed in the mid-1900s. Trout has been the victim of, for example, poor water quality of Haaganpuro caused by the sewage leaking into the water, illegal fishing, construction projects and noise from vehicles. Trout has been seen again in Haaganpuro successfully in the 2000s as the water quality improved during the last two decades. It has been used as an urban brook for spawning of sea trout. The trout population has been reviewed in recent years through fish planting and restorations, and it is seen that trout has been breeding successfully. Fishing in Haaganpuro is prohibited especially during spawning time which is in late autumn. [6] The ecological and recreational value of Haaganpuro was officially recognized in 2006 by its enclosure into the ambitious Helsinki small streams program. [7]

### **1.3 Objectives**

Urban streams and their water quality have been important subjects to research in Helsinki in recent years. In the city of Helsinki, the state of the river is observed by the city's environmental center on a regular basis sampling twice a year.

However, until now there has been lack of continuous and regular key research on water quality of specific streams separately. The main objectives of this thesis were the following:

- To study the overall condition of water quality of Mätäjoki and Haaganpuro.
- To compare the water quality of these two streams with each other.
- To compare the water quality of these two streams with past data.
- To study the concentration of nutrients in the streams.
- To understand the effects of different parameters in the water quality.

## 1.4 Background

Mätäjoki and Haaganpuro have been victim of pollution in the past due to various reasons which has affected the aquatic ecosystem as well as surrounding environment. In May 2013, around 500-1000 liters of solvent, Shellsol A 100 was leaked into Mätäjoki through storm drain from paint company named Teknos Oy located in Pitäjänmäki due to the negligence of the employees. Tens of thousands of fishes were found dead because of the solvent which is toxic to aquatic organisms. [8] This kind of environmental accidents and other human impacts have regularly degraded the quality of water in the urban streams. Haaganpuro and Mätäjoki have been home for endangered brown trout. The trout population has been revived through fish plantations and restorations in recent years in Haaganpuro and Mätäjoki, with the help of different organizations. Trout population carries a constant threat of water quality problem. Although, the quality of water in Haaganpuro and Mätäjoki is improving, it is still very important to monitor the water quality, to be sure there is not a problem associated with the trout population and overall urban ecosystem.

## 2 LITERATURE REVIEW

### 2.1 Water quality and parameters

The term water quality is a broad topic so it has different meaning to different people. Most used definition of water quality is "the chemical, physical and biological characteristics of water, usually in respect to its suitability for its designated use." Water is used for various purposes such as drinking, watering animals and plants on farms and raising

fish, and these designated uses have their own definition for chemical, physical and biological standards necessary to support that use. [9]

Water quality of urban streams is affected by both natural and human influences. Most common natural influences are geological, hydrological and climatic because these influences affect both the quantity and the quality of water resources. One example of natural influence is fresh water resources near coastal areas has a problem of high salinity. Human influences such as pollution of water resources by human feces or discharge of industrial water have been the problem especially in the developing countries. Other reasons for the depletion of water quality of fresh water has been the agricultural runoff and wastewater discharge that has affected the quality of water by the rising concentration of nutrients in the water sources resulting in problems such as eutrophication. [10]

There are physical, chemical and biological parameters that help to determine the quality of water resources. Physical parameters, for example, temperature, turbidity, color, taste and odor explain the physical characteristics of water. These parameters are determined using senses of touch, sight, smell and taste. Chemical parameters such as pH, electric conductivity, dissolved oxygen, heavy metals and nutrients explain the chemical characteristics of water and biological parameters help to identify the presence of microorganisms and water borne pathogens in the water. Examples of biological parameters of water quality are *E. coli* and total coliform. This thesis focuses on specific physio-chemical parameters such as temperature, pH, electrical conductivity, DO, heavy metals (total iron) and nutrients (total nitrogen and total phosphorus) to determine the water quality of Mätäjoki and Haaganpuro.

### **2.1.1 Temperature**

Water temperature is an important physical property expressing how hot or the cold the water resources are. It is affected by different factors such as temperature of air, groundwater inflow, exposure to the sunlight, turbidity and thermal pollution. Temperature plays an important role in the lives of aquatic animals and plants; thus, it is necessary to consider the maximum and the optimum temperature. Maximum temperature of water is the highest water temperature in which the aquatic lives can survive for a few hours, whereas optimum temperature is a suitable temperature for the aquatic lives to survive. Water temperature is also responsible for affecting the metabolic rates and biological activity of

the aquatic lives. It even affects the habitat of aquatic organisms; for example, aquatic plants are seen mostly in the warmer temperature, whereas fishes such as trout prefer colder temperature to survive in the water. Water temperature is directly proportional to the metabolic rate of the organisms as many cellular enzymes are more active in the warmer temperature. In Figure 3, it is seen that for most of the fishes, rise in 10 °C water temperature will approximately double the rate of physiological function. Temperature above 35 °C can result in breakdown of enzymes reducing metabolic function. Plants are also affected by the water temperature. For example, at temperatures below 21 °C, tropical plants restrict their growth and dormancy.

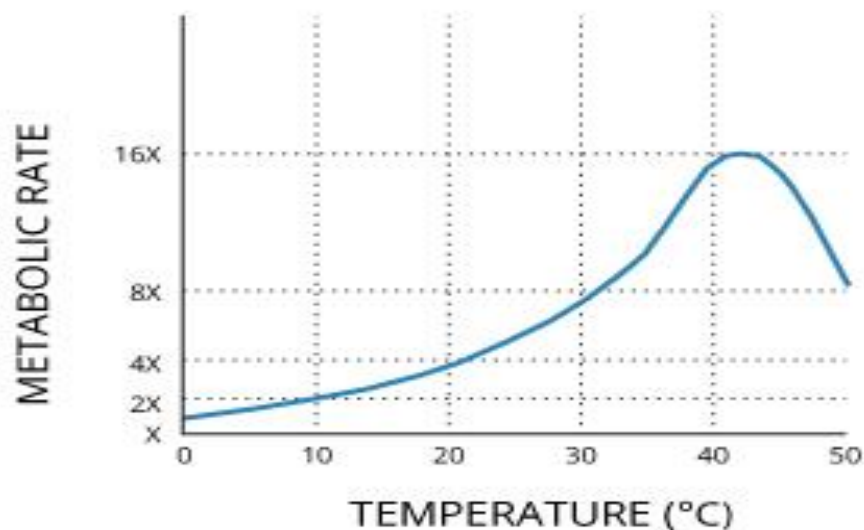


Figure 3. Relation between water temperature and metabolic rate of aquatic organisms [11]

Water temperature not only affects the aquatic organisms but also influences other parameters of water quality such as pH, compound toxicity, DO and other dissolved gas concentrations, conductivity and salinity, oxidation reduction potential, and water density. High water temperature can increase the solubility and toxicity of certain compounds, for example, ammonia and heavy metals such as zinc, cadmium, and lead. High water temperature not only increases the solubility of the compound but also affects the tolerance limit of the aquatic organisms. Water temperature is directly proportional to the density of water. The density of pure water decreases approximately by 9% when it freezes which is the reason why ice expands and float on the water. [11]



### 2.1.2 pH

pH is one of the most common test performed to determine the quality of water. It stands for 'power of hydrogen'. It is a measure of how acidic or basic the water is. pH is measured in the range of 0-14, where 7 is considered as a neutral. If the pH of water is less than 7, it is considered as acidic, and if it is greater than 7, it is considered as basic. In other words, pH can be defined as the measure of free hydrogen and hydroxyl ions in the water. If the water has more hydrogen ions, it is acidic, and if it has more hydroxyl ions, it is basic. pH is reported in 'logarithms unit' where each number represents 10-fold change in the acidity and basicity of water. As an example, water having pH of 5 is 10 times acidic than the water having pH of 6 and the water having pH of 9 is 10 times more basic than the water having pH of 8. Molar concentration of hydrogen ions ( $H^+$ )<sup>3</sup> determines the numerical value of pH which is calculated by taking the negative logarithm of hydrogen ion concentration ( $-\log(H^+)$ <sup>3</sup>). For example, if the solution has a concentration of  $(H^+) = 10^{-3}$ , the pH of solution is given by

$pH = (-\log(10^{-3}))$ , which is equal to 3 and shows that the solution is acidic.

In the case of neutral pH, the concentration of both hydrogen and hydroxyl ion is  $10^{-7}$ ; thus, these ions are always paired, which means concentration of one ion increases when concentration of other decreases. The sum of ions will always be  $10^{-14}$  regardless of the pH. [12]

There is greater importance of pH in determining the quality of water because it determines the solubility and biological availability of chemical elements, for example, nutrients such as phosphorus, nitrogen and carbon and heavy metals such as lead, copper and cadmium. For instance, it not only affects the quantity and form of chemical constituent such as phosphorus abundant in the water but also determines if the aquatic life can use it or not. In case of heavy metals, toxicity is determined by the degree of their solubility in the water. Metals are usually more toxic in the water with a lower pH as they are more soluble. [13]

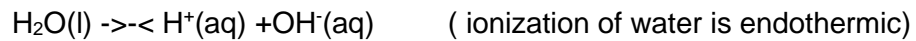
Aquatic organisms live in water with a specific pH. Most aquatic organisms cannot survive at too low or too high pH. These organisms prefer the optimum condition where the pH of water lies in the range of 6.5-9. If the aquatic organism is sensitive, it is more affected by the change in the pH of water. An extreme pH of water can increase the solubility of different chemical elements making the water toxic, which increases the risk



of absorption by the aquatic organisms. A slight change in pH level can cause eutrophication in the water resources. At a certain level of pH, the solubility of nutrients such as phosphorus is high and these nutrients are absorbed by the aquatic plants, for example, algae consuming a high amount of dissolved oxygen for their growth. This finally results in an overgrowth of those plants in the water resources demanding more dissolved oxygen. Lack of dissolved oxygen in the water resources causes death of aquatic organisms. Not only aquatic organisms but also human beings are affected by certain pH levels. Water with a pH greater than 11 and less than 4 can cause eye and skin irritations. Similarly, water with a pH less than 2.5 will cause irreversible damage to skin and organ linings. [12]

pH is affected by many factors and those factors are natural and man-made. Most of the natural changes take place due to the interaction of water sources with the surrounding rocks and other materials. Precipitation such as acid rain can also change the pH of water resources making it more acidic and the concentration of carbon-dioxide can alter the level of pH. Carbon dioxide is considered as one of the major factors affecting the pH of water. Carbon dioxide has been increasing in the atmosphere due to the reason of global warming and the dissolved  $\text{CO}_2$  shows inverse relationship with the pH. That means higher the concentration of dissolved carbon dioxide in the water lower the pH is. In other words, we can say water with high concentration of dissolved  $\text{CO}_2$  is acidic in nature. Carbon dioxide is released to the water resources, for example, from the atmosphere, through surface runoff and by respiring aquatic animals and microbes. Another factor affecting the pH of water is acid rain resulting from pollution caused by humans. It is caused when sulfur dioxide ( $\text{SO}_2$ ) reacts with nitrogen oxide (NO) in atmosphere combining with water vapor. Acid rain is one reason for water resources being acidic. Dissolved minerals from groundwater, where there is limestone bedrock can increase the alkalinity of water by raising the pH level, and wastewater discharge from individuals, industries, and municipalities containing different chemicals, for instance, cleaning agents and detergents increase the alkalinity of the water resources. [14]

In addition, temperature affects the pH of water. Temperature and pH are inversely related to each other. With the increase in the temperature, the pH of water decreases and with the decrease of the temperature, the pH of water increases. At pH 7, both hydrogen and hydroxyl ions have concentrations of  $1 \times 10^{-7}$  M making the solution neutral, which is only true at the temperature of  $25^\circ\text{C}$ . Increase or decrease in the temperature of water shifts the concentration of ions shifting the pH value which is explained by Le-Chatelier's Principle.



When the temperature of the water is increased in left, heat is added in this equilibrium system and per the Le-Chatelier's Principle the equilibrium will counteract the addition of heat by shifting it to the right. As the addition of heat is shifted towards right, the concentration of hydronium and hydroxyl ions increases by the same amount. As the concentration of hydronium ion increases, pH of water decreases. But it is important to know that the water remains neutral because the concentration of both the ions is equal since they increase by the same amount. Change in temperature never makes pure water acidic or basic, it always remains neutral. Solution is acidic only if the concentration of hydronium ion is greater than the concentration of hydroxyl ion. [11] Relation between pH and temperature can be seen in Figure 4.

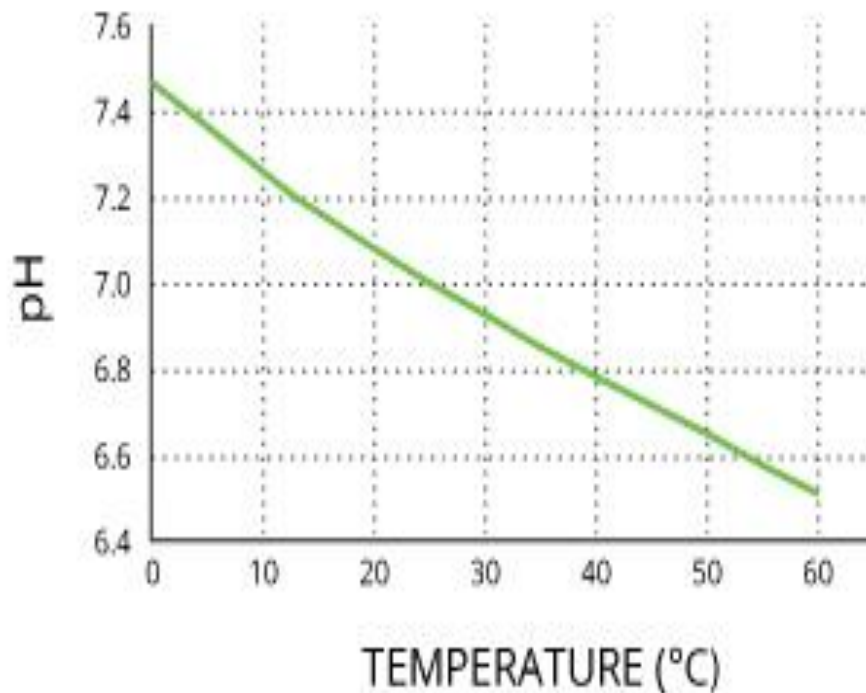


Figure 4. Relation between pH and water temperature [11]

Table 1 shows the value of  $K_w$ , pH and POH in different temperatures.

Table 1. Value of  $K_w$ , pH and pOH in different temperatures [15]

T (°C)	$K_w$ (mol <sup>2</sup> dm <sup>-6</sup> )	pH	pOH
0	$0.114 \times 10^{-14}$	7.47	7.47
10	$0.293 \times 10^{-14}$	7.27	7.27
20	$0.681 \times 10^{-14}$	7.08	7.08
25	$1.008 \times 10^{-14}$	7.00	7.00
30	$1.471 \times 10^{-14}$	6.92	6.92
40	$2.916 \times 10^{-14}$	6.77	6.77
50	$5.476 \times 10^{-14}$	6.63	6.63
100	$51.3 \times 10^{-14}$	6.14	6.14

In Figure 4 and Table 1, we can see that the value of pH and pOH is increasing with the increase of the temperature. We can also see that the value of pH and pOH are same for the same temperature which is because the concentration of hydrogen and hydroxyl ions increase by the same amount with the increase of the temperature. We can see that the value of pH is below 7 from temperature 30 °C to 100 °C; however, we cannot conclude that the water is acidic at those temperatures. For the water to be acidic, pH should be below 7 only when the temperature is at 25 °C. [15]

### 2.1.3 Electrical conductivity

Conductivity of water is a measure of capability of water to pass an electrical flow. It is measured in the unit, Siemens per meter (S/m) in SI unit. For the measurement of fresh-water, micro Siemens per centimeter is the standard unit. Conductivity is denoted by the symbol  $k$  or  $s$ .

Conductivity is directly related with the concentration of ions in the water solution, and these ions come from dissolved salts and inorganic substances in the water, for example, alkalis, sulfides, chlorides and carbonated compounds. These compounds are also known as electrolytes that dissolve in the water as ions. Electrical conductivity of water is high when there are more free ions present in the water and conductivity is low when

the number of free ions present in the water is low. Ions can conduct electricity because they have positive and negative charges. Therefore, when electrolytes dissolve in the water, they split into positive and negative charges. Positive charge is known as cation and negative charge is known as anion. Concentrations of each positive and negative charge remain equal when the electrolytes split in the water, which means water remains electrically neutral although water's conductivity increases with added ions. [16]

Pure water is a bad conductor of electricity because the concentration of free ions in the pure water is very low. Ordinary distilled water in equilibrium with carbon dioxide in the atmosphere has a conductivity of 20 dS/m. Typical Conductivity for several types of water are listed below:

- Ultra-pure water:  $5.5 \times 10^{-6}$  S/m
- Drinking water: 0.005-0.05 S/m
- Seawater: 5 S/m

Seawater has a high conductivity due to the greater number of free ions present in the water because of salt present in the sea water. [17]

The main source of conductivity in fresh water is the geology of surrounding environment. Clay soil is one of the source that increase the conductivity of water. The minerals present in the clay are ionized as they dissolve in the water. Similarly, the groundwater that flows to the freshwater sources also contribute to the conductivity depending on the geology of the groundwater. If the groundwater is rich in minerals that can ionize, it will increase the conductivity of fresh water source where it flows.

Conductivity is an important parameter to determine the water quality. It shows an early indication if there is any change in the water system. Most of the water bodies uphold constant conductivity so it can be used as a reference line of evaluation for the future measurements. If there is any notable change in conductivity of water resources, we can predict that the change is caused by several reasons such as pollution, flooding and evaporation, and this will help to minimize those environmental problems to maintain the good water quality. Conductivity and salinity are strongly correlated to each other so salinity and TDS which affect water quality can be estimated easily with the help of conductivity. Salinity is important because it affects the solubility of dissolved oxygen. The higher the salinity of water, the lower the concentration of dissolved oxygen in water. At the same temperature oxygen is about 20% less soluble in seawater than in fresh water. [16]

Conductivity is an indirect measurement of water salinity. Aquatic organisms such as fishes that survive in fresh water cannot tolerate a significant increase in the salinity of water because they cannot keep water in their bodies. Thus, high conductivity of water means the more negative effect to aquatic organisms. [18]

### **Factors affecting conductivity**

There are numerous factors responsible for the change in conductivity of water. The main reasons for the fluctuation of conductivity are temperature and salinity/TDS. Conductivity of water fluctuates daily because of temperature. Water flows from one source to another and water level also affect the conductivity of water because of their impact on salinity of water. Change in water level due to evaporation of water will increase the salinity and conductivity of water. Similarly, the rain can increase the water level that decrease the conductivity of water. [16]

Water temperature and conductivity are related with each other. Increase in the water temperature will cause a decrease in the viscosity of water and an increase in the mobility of ions in a water. Also, the increase in the temperature of water can cause an increase in the number of ions in a water solution because of separation of molecules. As conductivity is directly related to the number of ions and their mobility in the solution, increase in the water temperature will increase the conductivity of the water. [19]

There is approximately 2-3% increase in the conductivity with 1 °C increase in the temperature, where in case of pure water it increases by 5% with 1 °C increase in the temperature. This is the reason why many professionals use specific conductance, which is a standardized comparison of conductivity that is temperature corrected to 25 °C. Solubility of many salts is directly proportional to the temperature of water. Higher the temperature of the water, more salts are soluble in the water. Water with a higher temperature can dissolve several minerals and salts more easily than the water with a low temperature. Increased minerals and ions content can be seen in natural hot springs which has healing abilities. Among different salts there are some salts that are less soluble in warmer temperature that inversely affect the conductivity which can be seen below in the Figure 5. [20]

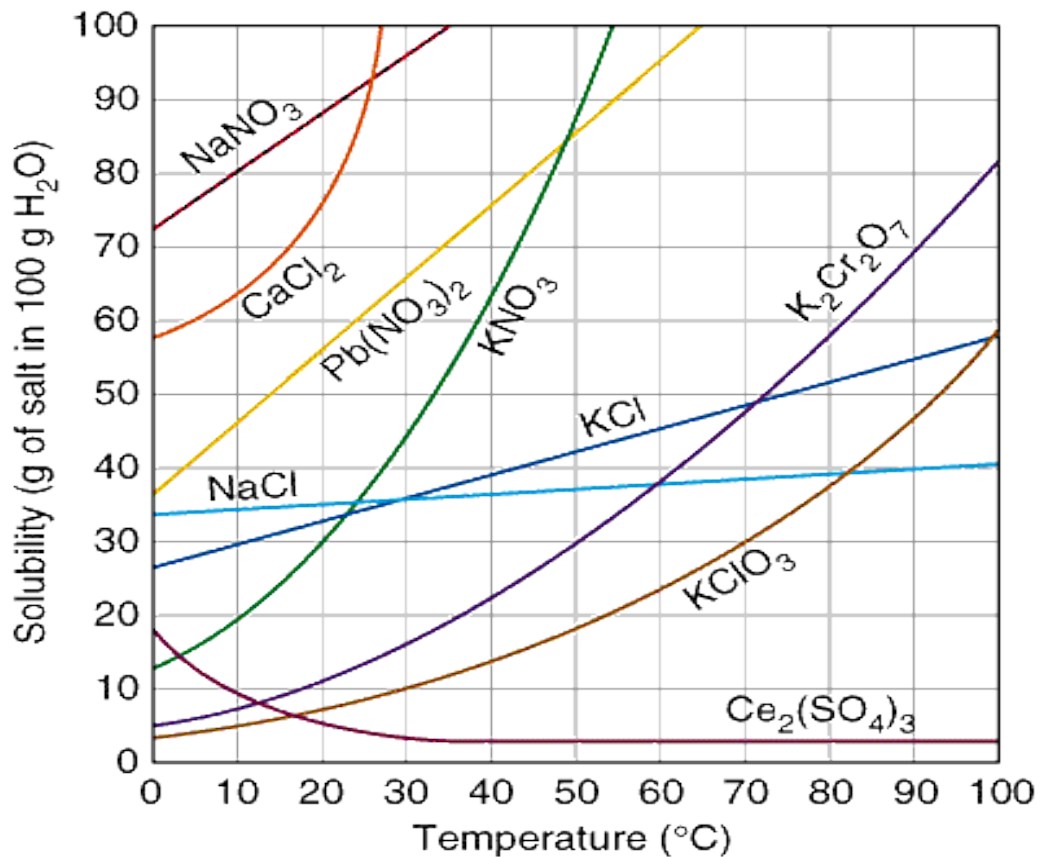
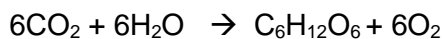


Figure 5. Relation between water temperature and solubility of salts [21]

#### 2.1.4 Dissolved oxygen

It is the amount of oxygen molecule that is dissolved in the water. It is measured in milligrams per liter. The oxygen gets dissolved into the water by different process, for example, diffusion from the surrounding air, aeration into the water and as a waste product of photosynthesis.

Photosynthesis in the presence of light and chlorophyll gives:



Aquatic animals such as fishes cannot split oxygen from the water molecules ( $\text{H}_2\text{O}$ ) or from other oxygen-containing compounds. Oxygen can be split from those compounds with the help of green plants and some bacteria through the process of photosynthesis and other similar process. Oxygen is one of the most essential element for the aquatic organisms to survive. Without the presence of enough oxygen, aquatic life is not possible. [22]

Dissolved oxygen is one of the most important parameter in determining the quality of water as it has a huge influence on the organisms living in the water bodies. Amount of dissolved oxygen needed is different for different species.

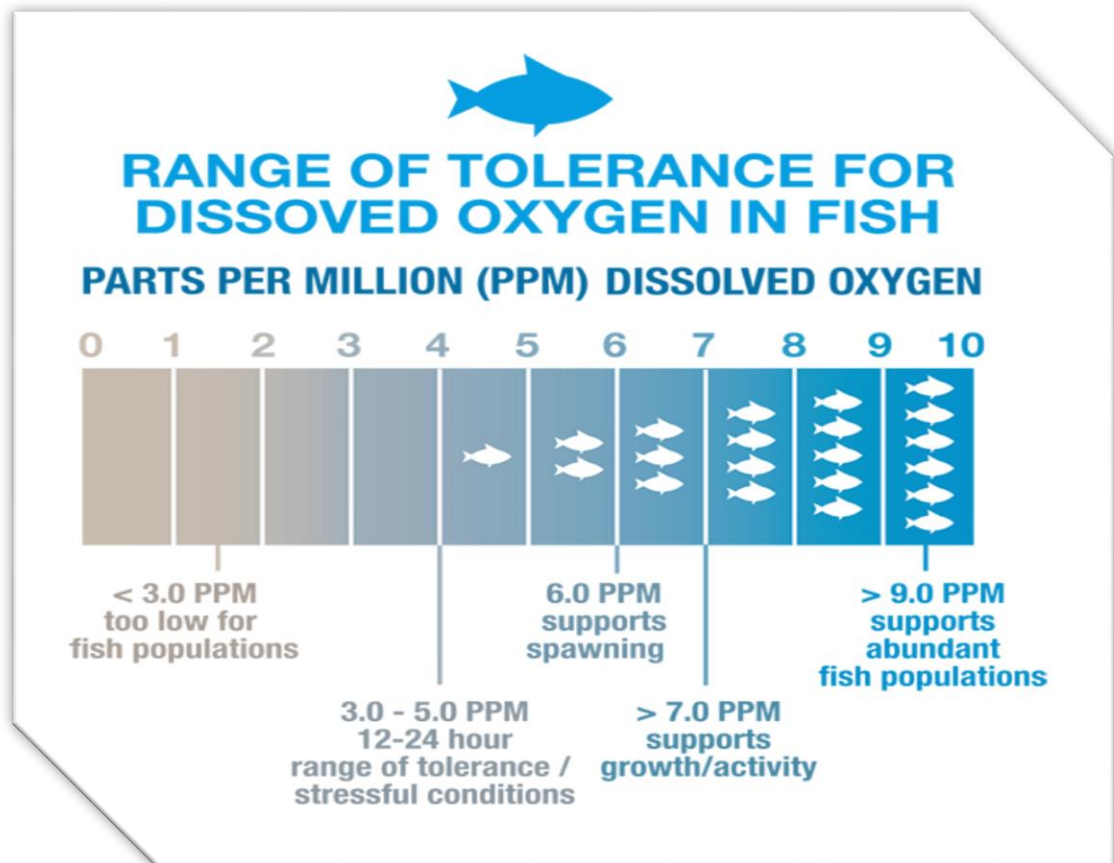


Figure 6. Range of tolerance for DO in fish [23]

Trout needs about five to six times more DO when the temperature is at 24 °C in comparison when the water temperature is 4 °C. As the metabolic rate increases with the increase of the water temperature, more amount of DO is needed for the aquatic organisms such as trout to support their increased metabolic rates. Figure 6 shows that the minimum amount of DO needed for fishes to survive is 4 to 5 mg/l. Fishes cannot survive in the water having DO below 3 mg/l. DO above 7 mg/l supports growth and activity of fishes and above 9 mg/l it supports abundant fish populations. Depletion of DO in the water bodies can cause shifting of the organisms living in the water. In case of a low level of DO, pollution tolerant organisms, for example, flying larvae and worms will replace the organisms such as mayfly nymphs, stonefly nymphs and beetle larvae that cannot survive in low level of DO. Organisms, for instance, nuisance algae and other



anaerobic organisms that does not need oxygen become abundant in the water bodies where there is very low amount of DO present. Certain type of pollutants present in the water can restrict the oxygen uptake and metabolism. So, if such pollutants are present in the water, some aquatic organisms may need higher level of DO. [23]

One of the way to assess the quality of water bodies with fair accuracy is by witnessing the population of aquatic organisms. Table 2 indicates the normal tolerance of different organisms to temperature and DO levels.

*Table 2. Normal tolerance of different aquatic organisms to temperature and DO [24]*

Aquatic Organism	Temperature Range (°C)	Minimum DO level (mg/l)
Trout	5-20	6.5
Smallmouth bass	5-28	6.5
Caddisfly larvae	10-25	4.0
Mayfly larvae	10-25	4.0
Stonefly larvae	10-25	4.0
Catfish	20-25	2.5
Carp	10-25	2.0
Mosquito	10-25	1.0
Water boatmen	10-25	2.0

Concentration of dissolved oxygen also affects some chemicals present in the water. As an example, some metals, for example, cadmium solidify and sink out of water in the presence of oxygen and without oxygen such metal dissolves into the water in a form which is highly poisonous to aquatic organisms. [25]

### **Factors affecting DO in water**

There are both natural and human factors responsible for the change of DO in the water resources. Natural factors include the following:

- Aquatic life: Aquatic organisms use oxygen for their survival. Organisms such as bacteria need oxygen to decompose the materials. So, the water containing



large amount of dead and decomposing materials have low level of DO as most of the DO is used by the bacteria.

- Flow and velocity of water: Fast moving streams have high level of DO as running water is aerated with bubbles as it agitates over rocks and falls down hundreds of tiny waterfalls. In slow and stationary water, oxygen enters only at the top layer of the water. The deeper part of the water is very low in DO because bacteria that live at the bottom of the water use oxygen for the decomposition of organic matters.
- Climate/Season: More oxygen can be dissolved in the cold water. So, the level of DO in a certain place is higher in winter than in the summer.
- Altitude: Oxygen is dissolved more easily in the water which are at low altitude than in high altitudes because low altitudes have higher atmospheric pressure.
- Vegetation: Riparian vegetation helps in increase of DO level in the water bodies by releasing oxygen during the process of photosynthesis. Also, the vegetation shading helps to decrease the temperature of water bodies. As the DO is inversely related with the water temperature, decrease in the temperature of water bodies will increase the level of DO in the water.
- Groundwater inflow: Although the groundwater has low level of DO than the stream, it helps to increase the DO in stream by cooling the water of stream as it is colder than the stream. Low temperature of water means high level of DO.

Human factors responsible for the change in DO level in the water resources are as follows:

- Destruction of Riparian vegetation: Destruction of such vegetation by human depletes the level of DO in the water. Destruction of vegetation decrease the amount of shade that increase the temperature of water finally decreasing the level of DO in the water. And when there is no vegetation, it means there is no photosynthesis and no photosynthesis means, there is not any release of oxygen.

- Nutrient pollution: Nutrients such as phosphorous and nitrogen get into the water bodies because of human activities such as agriculture and industries. Such nutrients get into the water bodies due to land runoff and industrial water discharge. When concentration of nutrients is high in the water, it supports the growth of algae blooms. When the algae die, bacteria use lot of DO to decompose algae resulting in low level of DO in the water.
- Clearing land: Clearance of land for various purposes such as construction and logging may transport excess amount of organic matters into the water bodies. Organic matters are decomposed by the microorganisms such as bacteria. So, high amount of organic matter in the water result in high consumption of DO by the microorganisms for the decomposition process.

[26] [27]

In addition, one of the key factor affecting dissolved oxygen in the water bodies is temperature. Dissolved oxygen is inversely proportional to the temperature. The solubility of oxygen and other gases decreases when the temperature of water increases. So, the colder water can hold more DO than the warmer water. Figure 7 shows the relation between the water temperature and the oxygen content of the river. [28]

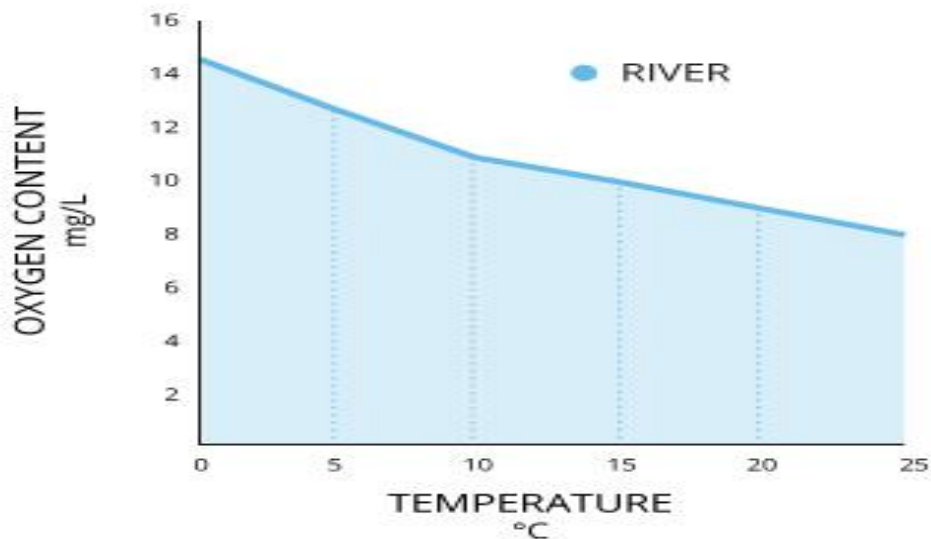


Figure 7. Relation between DO and water temperature [28]

### 2.1.5 Turbidity

Turbidity is one of the important physical parameter for the determination of water quality. It is a cloudiness of water caused by the suspended particles that are usually invisible to naked eye. Turbidity is an optical feature of water and is an expression of the amount of light that is dispersed by particles in the water when a light is passed through the water sample. It is directly related to the intensity of scattered light. Higher intensity of scattered light means higher turbidity. So, it shows how well the light can pass through the water. Water contains different solid particles with a different size. Large particles settle at the bottom due to their high density, whereas small particles get suspended on the surface and try to settle very slowly. These types of different particles cause water to look unclear or turbid. [29]

Normally turbidity is measured by an instrument called a Nephelometer. This instrument measures turbidity in standard Nephelometric Turbidity units (NTU) by determining the scattering of light. The level of turbidity normally varies from less than 1 NTU in very clear streams to much greater than 200 NTU in cloudy rivers after floods. [30] The WHO has established the level of turbidity in the drinking water per which the turbidity of drinking water should not be greater than 5 NTU and it should ideally be below 1 NTU. [31]

#### Causes of Turbidity

There are several factors responsible for increase of turbidity in the water. Major factors are as follows:

- **Soil erosion:** Heavy rainfall and increase in streamflow can result in the soil erosion. Soil erosion is the shifting away of top layer of soil due to the natural factors. This shifting away of soil containing particles, for example, clay and slit reaches to the water resources that increases the suspended particles in the water finally causing turbidity.
- **Urban runoff:** Urban runoff of several types contain the suspended solids that affect the turbidity of the water resources. Urban runoff from roads, rooftops, agricultural runoff, runoff from industries and water treatment plants cause increase in the turbidity of water resources.
- **Industrial waste:** Industrial discharge of water containing various pollutants and particulates larger than 2 microns contribute in concentration of total suspended solids. Colored wastewater discharge and dyes are example of pollutants that

affect turbidity of water. Although the nutrients such as nitrate and phosphorus are soluble in the water, they are considered as indirect contributor because they cause algal blooms which affect the turbidity of water.

- Abundant bottom dwellers: Different bottom-dwelling aquatic organisms such as catfish can increase the turbidity of water resources as they stir up the sediments present at the bottom of the water resources.
- Algae growth: Excessive algae growth resulting in the algal blooms because of high concentration of nutrients is one of the contributor to the turbidity. Algal blooms floating on the water can block the sunlight and can release the toxins and decrease the level of DO in the water.

Organic matters such as Plankton or decaying of different plant and animal matter that is suspended in the water can also increase the turbidity of the water. Similarly, the oil and gas spills on the roads flowing to the water resources along with the rain can also increase the turbidity of water resources. [32]

One of the key factors that influence the level of turbidity in the water resources is water flow. Turbidity is directly related with the water flow. Higher flow rates of the water keep particles suspended in water instead of letting them settle to the bottom. This is the reason why in rivers and streams where the flow is high, turbidity is seen constant. As heavy rainfall increases the volume and flow of the water, turbidity of water increases as settled sediments are again re-suspended in the water. Figure 8 shows the relation between the water flow and turbidity in the stream. [33]

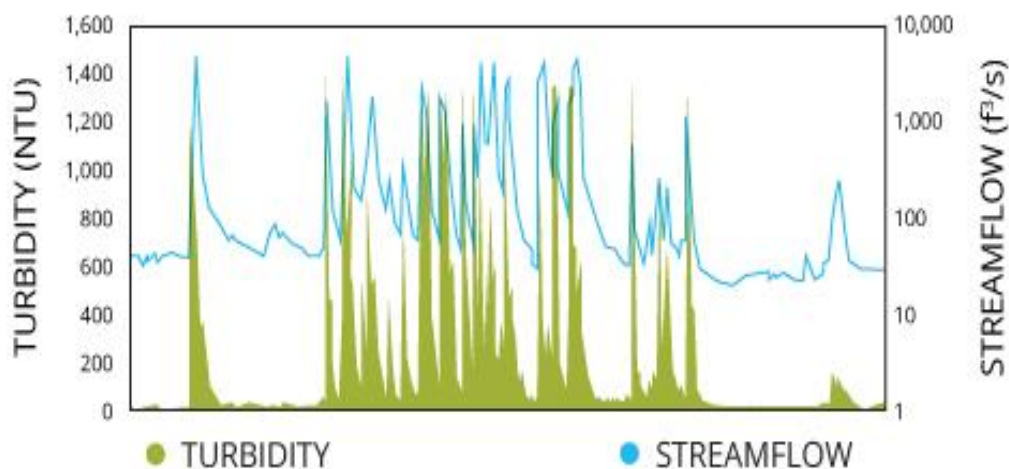


Figure 8. Relation between turbidity and streamflow [33]

### Impacts of Turbidity

There are physical, chemical and biological effects of turbidity in the water resources. They are as follows:

- Fine sediments can cause clogging of channel bed, marginal changes to the stream channel morphology reducing habitat for small fishes and invertebrates. Also, reduces the permeability of the bed material.
- Increase in the turbidity, increase the temperature of water. Turbidity is the result of suspended particles in the water. These suspended particles absorb heat from sunlight more efficiently than the water. Absorbed heat by the particles is transferred to the water molecules causing increase in the temperature of water resources.
- Increase in turbidity prevents the sufficient light entering the water that affects the photosynthesis process. Without photosynthesis process, aquatic plants die. Many aquatic plants are source of food for different aquatic organisms. Death of these plants causes lack of food to the organisms and affect the food chain.
- As a chemical impact, high turbidity level can decrease the concentration of DO in the water. This is because increase in the turbidity increase the water temperature and increase in the water temperature decrease the concentration of DO. Lack of photosynthesis due to turbidity also decline the concentration of DO in the water resources.

Beside these impacts, high turbidity also causes physical damage to the surface of leaves by scratch and smothering. It affects the aquatic organisms, for example, salmonids and other fish species by interfering with their behavior and growth. It affects by preventing successful development of fish eggs and larvae. Turbidity also can cause damage to fish gills by scratching and clogging. Particles of 2-3 p.m. are mostly responsible for the gill abrasion in the salmonids population. High turbidity may also increase vulnerability of fishes to disease. When mucus separated by fish is in response to high concentration of suspended solids, there is high chance to attract bacteria and fungus.

[34]

### 2.1.6 Metals

Different type of metals such as iron (Fe), manganese (Mn), zinc(Zn), lead (Pb) and copper (Cu) are essential in different biochemical process to sustain life in certain concentrations. These metals however in high concentrations are toxic to aquatic organisms and even can be toxic to human beings if they are ingested directly in the water or when human beings consume aquatic organisms such as fishes living in water of high metal concentration. The toxicity and bioavailability of metals depend on their oxidation state and the form they occur. Water soluble metals are more bioavailable and toxic than the metals which are found in complex form with other molecules or which are adsorbed to sediment particles. Chemical characteristics of water such as pH, hardness, DO levels affect metal's characteristics, for instance, solubility, oxidation state and toxicity. Metals occur naturally in the water sources from weathering of rocks and soils. Soil erosion and sedimentation carry these metals into water resources. Another source of metals in water bodies is waste water effluent, for example, water discharge from different industries. [35]

Total iron was one of the parameters analyzed during this thesis project. It is the fourth most abundant element by weight found in earth's crust. It is present in different quantities depending on the geological area and other chemical components of water bodies. Normally it is present in the form of soluble ferrous ( $\text{Fe}^{++}$ ) in groundwater which can be easily oxidized to insoluble ferric ( $\text{Fe}^{+++}$ ) state when it is exposed to air. Ferrous and ferric ions are the primary states of concern in the aquatic environments. Iron can be present in other forms in organic or inorganic wastewater streams. Iron in ferrous state can persist in the water with no DO and generally originates from groundwater wells. Black or brown marsh of water may contain iron of several mg/l in the presence or absence of DO which has very tiny effect on the aquatic life. The current limit of iron concentration for aquatic life is less than 1.0 mg/l based on toxic effects. [36]

The main source of iron in the water bodies is weathering of iron minerals such as magnetite, hematite, goethite and siderite which is a natural process. Weathering of these minerals releases iron in the water bodies. Other ways how iron can get into the water bodies are industrial discharge, refining of iron ores and soil erosion. Water pollution related with construction and iron mining can increase the construction of iron in the water. Iron gets into the groundwater when the soil and rocks containing iron get in contact with the rain water. This water dissolve iron and finally deposit it into the aquifer. When this groundwater mix with river water, it can increase the iron concentration of river water. [37]

The concentration of iron in the river water is approximately 0.5-1 ppm of iron and the groundwater contains 100 ppm of iron. Seawater has approximately 1-3 ppb of iron and the concentration varies for example the concentration of iron in Atlantic and Pacific Ocean is different. Iron concentration in drinking water may not be more than 200 ppb of iron. Iron in the water resources is accumulated by the aquatic organisms. Most of the algae has 20-200 ppm of iron. Brown algae may accumulate iron up to 4000 ppm. Dissolved iron can be found as  $\text{Fe}(\text{OH})_2^+$  (aq.) in acidic, neutral and oxygen rich conditions. Iron does not change in pure water or dry air but when it gets contact with water or moist air containing oxygen it gets corrode changing its silver color to reddish-brown because of the formation of hydrated oxides. [38]

A certain concentration of iron is beneficial to aquatic life. Iron promotes enzyme growth and gives red color to blood. In fresh water, it is an important nutrient for algae and other organisms that supports their growth. Due to the reason that iron is abundant in the earth's crust, it is found in every freshwater environment and is present in higher concentration in the water and sediments than other trace metals. Effects of high concentration of iron are as follows:

- High concentration of iron is toxic to aquatic organisms. When the iron in the water is at higher level, aquatic organisms cannot process all the iron. The iron can build up the internal organs of organism finally killing them. Iron toxicity plays role in damaging DNA and membrane damage of the organisms. Vertebrate studies have shown that high cellular concentration of iron may cause cell degeneration. Increase in iron load can significantly change both structure and function of aquatic ecosystem.

Similarly, high concentration of iron in fish and aquatic plants can harm human beings when they consume those aquatic organisms affected by high concentration of iron. [39]

- High concentration of iron increases the growth rate of algae which can result in algal bloom. Algal bloom can reduce the freshness of the water and it can block the sunlight passing to the water that can hamper the photosynthesis process resulting in decline of DO in the water. Increased concentration of iron sometimes increases the acidity of water. Iron contamination can affect the feeding habit and reproduction of aquatic organisms. [40]

- Increase in the iron concentration can change the color of water bodies. Iron is considered as a possible source of color. It is known to contribute to light absorbance and color in freshwaters. Generally, increase in the water color is known to be affected by the increasing concentration of dissolved organic matter. However, it is seen that presence of iron along with organic matter affect water color more than the organic matter alone. [41]

### 2.1.7 Nutrients

Nutrients are the most important parameters in determining the water quality of fresh waters, for instance, streams and lakes. They are chemical elements which are crucial to the development of plant and animal life. Nutrients in normal concentration are needed for the algal growth to form the base of complex food web that can support the entire aquatic ecosystem. However, the excess of the nutrients in the water bodies support the growth of algae beyond the amount needed to support the food web. Excess growth of algae results in algal bloom. Later when the algae die microorganisms break it down consuming DO in the water bodies. DO can be completely used up to decompose excess algae in the water that can result in death of aquatic life due to lack of oxygen. Most common nutrients found in the water bodies are nitrogen and phosphorous. [42]

#### Nitrogen

Nitrogen is the seventh most abundant element in the earth. It is denoted by N and has an atomic number 7. About 78% of Nitrogen is found in the atmosphere. It is found in the soils and some minerals, plants, fresh and marine waters and in every ecosystem and is a part of global environment. Nitrogen is a vital component of different critical molecules, for example, amino acids, nucleic acids and proteins. [43]

Nitrogen is found in different forms. Nitrogen present in the atmosphere is in the form of gas known as dinitrogen ( $N_2$ ). Dinitrogen can also be found in soils but plants cannot use this form of nitrogen. In addition to dinitrogen, nitrogen is present in other organic and inorganic forms. Nitrogen in the soil is mostly found in organic form. Inorganic nitrogen is found in various states of oxidation, from -3 in the most reduced form (ammonium) to +5 in the most oxidized form (nitrate). Plants use only very specific inorganic forms of nitrogen such as ammonium ( $NH_4^+$ ) and nitrates ( $NO_3^-$ ). Nitrate is used for growth and



development of the plants, whereas ammonium absorbed by the plants is directly used in the proteins. [44]

Nitrogen moves across the earth in a cycle called *nitrogen cycle*. It can be defined as a collection of different processes, most of them resulting from microbial activities, that convert nitrogen into different usable forms and finally returns nitrogen gas back to the atmosphere. [45] Nitrogen is important to life because it is a major component of proteins and nucleic acids. It has a high demand in biological systems. Nitrogen occurs in various forms such as organic, inorganic and gaseous and is continuously cycled among these forms by different complex chemical and biological changes. Nitrogen is abundant in the atmosphere in the form of dinitrogen which is extremely stable, so conversion to other different forms need high amount of energy. Biologically available forms of nitrogen such as  $\text{NO}_3$  and  $\text{NH}_3$  have been often limited in the past but currently due to different process such as fertilizer production, it has increased the accessibility of nitrogen to living organisms. [46] Nitrogen cycle can be explained in five steps:

- Nitrogen fixation
- Nitrification
- Assimilation
- Ammonification
- Denitrification

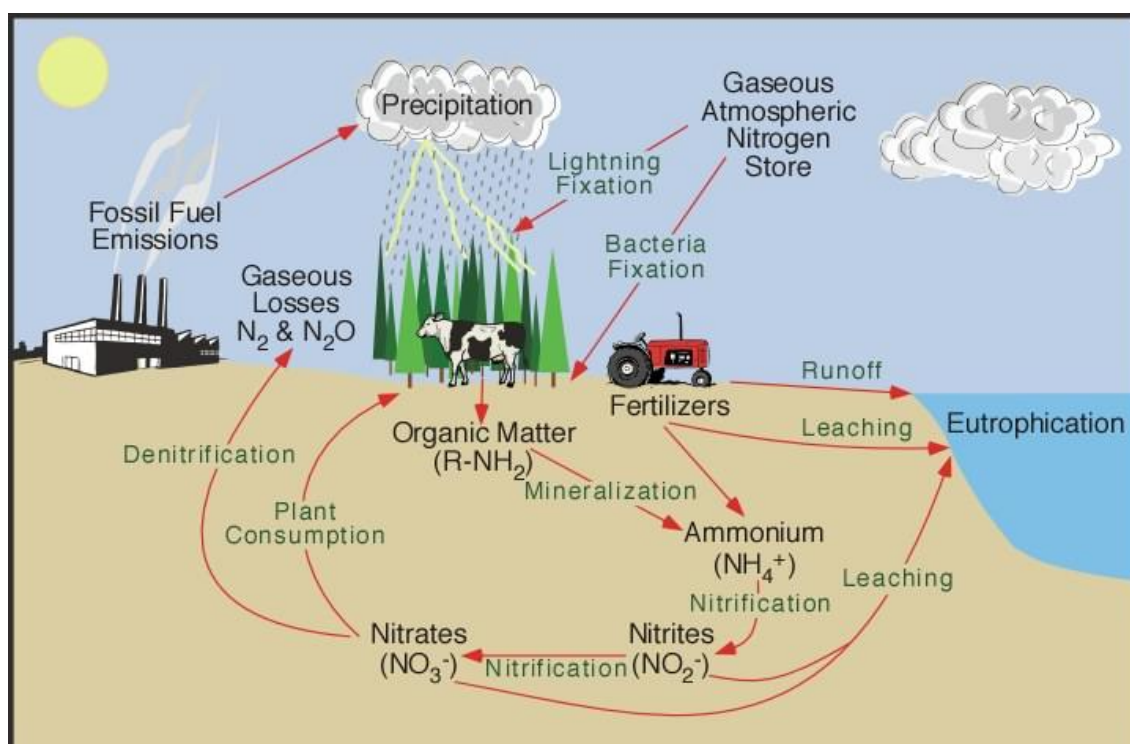
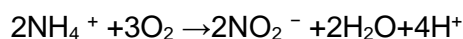


Figure 9. Nitrogen cycle [47]

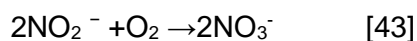
*Nitrogen fixation* is a process by which gaseous nitrogen ( $N_2$ ) is converted to ammonia through biological fixation and to nitrate ( $NO_3^-$ ) through high energy physical process. Nitrogen fixation can occur in several ways. Nitrogen present in the atmosphere is very stable and needs great amount of energy to break down the bonds between two N atoms. During lightning, large amount of energy is released that breaks down the nitrogen molecules into atoms. These nitrogen atoms combine with the oxygen in the atmosphere to form  $NO_x$ . When these nitrogen oxides dissolve in rain, they form nitrates that finally come to earth along with the rain. Some ammonia is also produced in industries by Haber-Bosch process using iron based catalyst in high pressure and temperature. Major conversion of nitrogen to ammonia is achieved by microorganism through biological process. Some bacteria and cyanobacteria can break the nitrogen molecule into atom and combine it with the hydrogen with the help of enzyme known as *nitrogenase*. This enzyme only functions in the absence of oxygen. One of the example of bacteria that can fix nitrogen is *Rhizobium*, that live in oxygen free zone in nodules on the roots of legumes and other woody plants. [46]

*Nitrification* is a process in which ammonia or ammonium ion is biologically oxidized to nitrite and then to nitrate. Most of the nitrification processes occur aerobically and are performed entirely by prokaryotes. Nitrification occurs in two steps which are carried out by different type of microorganisms:

1. Oxidation of ammonia or ammonium to nitrite. This is performed by ammonia-oxidizing bacteria such as *Nitrosomonas*.



2. Oxidation of nitrite to nitrate. This is performed by nitrite-oxidizing bacteria such as *Nitrobacter*.



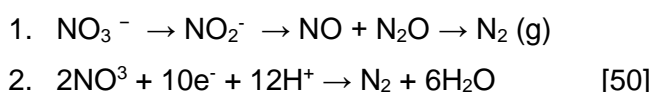
*Assimilation* is a process by which plants and animals incorporate the  $NO_3^-$  and  $NH_3$  formed through the process of nitrogen fixation and nitrification. These forms of nitrogen are incorporated by plants into organic substances, for example, proteins, amino acids, nucleic acids and chlorophyll through their roots. Animals then utilize nitrogen from the plant tissues. [46] Plants absorb  $NO_3^-$  and  $NH_4^+$  from the soil with the help of their root hairs. When  $NO_3^-$  is absorbed, it is first reduced  $NO_2^-$  and then to  $NH_4^+$  for the incorporation into different organic components such as amino acids. Plants that have symbiotic

relationship with Rhizobia can assimilate N directly from the nodules in the form of ammonia. [48]

*Ammonification* is the process of converting organic nitrogen produced from assimilation to ammonia. Ammonification is the result of decomposition of organic matters such as dead plants, animals and their waste materials. When plants and animals die, microorganisms break down the organic matter for energy and produce ammonia and other related compounds as a byproduct of their metabolisms. This process occurs in the soil in aerobic condition. [49]

*Denitrification* is the reduction of  $\text{NO}_3^-$  to gaseous  $\text{N}_2$  with the help of anaerobic bacteria. It is the last step that completes the nitrogen cycle. Reduced nitrogen gas goes back to the atmosphere. Since it is an anaerobic process, it occurs in those places such as soils, sediments and anoxic zones in lakes and oceans where there is very little to no oxygen. Denitrifying bacteria, for example, *Pseudomonas* reduces nitrates to nitrogen gas.

The following reactions show the stepwise reduction of nitrate to dinitrogen gas and the complete denitrification process expressed as a redox reaction, respectively:



## Phosphorus

Phosphorus is a chemical element with atomic number 15. It is denoted by P. It is an important nutrient for plants and animals. It plays a key role in development of cell and is a major component of molecules that store energy, such as ATP, DNA and lipids. [51] It can be found in water, soil and sediments on earth however, it cannot be found in gaseous state. This is because P is usually liquid at normal temperatures and pressure. Phosphorus mainly cycles through water, soil and sediments. It can be found in the atmosphere as very tiny dust particles. [52]

Phosphorus occurs normally as orthophosphate ( $\text{PO}_4^{3-}$ ) in nature. It is found in different minerals such as olivine, pyroxene and amphibole, and it is present in biological components such as bone and is a major element in plants. Aqueous geochemistry of phosphorus is very complex. P in fully oxidized form,  $\text{P}^{5+}$  that occurs as  $\text{PO}_4^{3-}$ ,  $\text{HPO}_4^{2-}$  or  $\text{H}_2\text{PO}_4^-$  depending on the pH, is the main oxidation state of significance in natural water systems. Inorganic polyphosphate and organic phosphorus compounds, mainly as complexes with organic acids are other forms of dissolved phosphate. About 50 % of phosphorus from total phosphorus is in organic form. [53] Amount of P in soil is generally low

that affects the plant growth. This is the reason why phosphate fertilizers are used in agriculture.

Phosphorus moves across the Earth in a cycle called *phosphorus cycle*. It is one of the slowest biochemical cycle that describes the movement of phosphorus through lithosphere, hydrosphere, and biosphere. Since P and P-compounds are usually in solid state at typical range of temperatures and pressures, atmosphere does not play any key role in the movement of phosphorus. [54] P moves through rocks, water, soil and sediments and plants and organisms. Main steps of P-cycle are given in Figure 10 and explained in more detail below the figure.

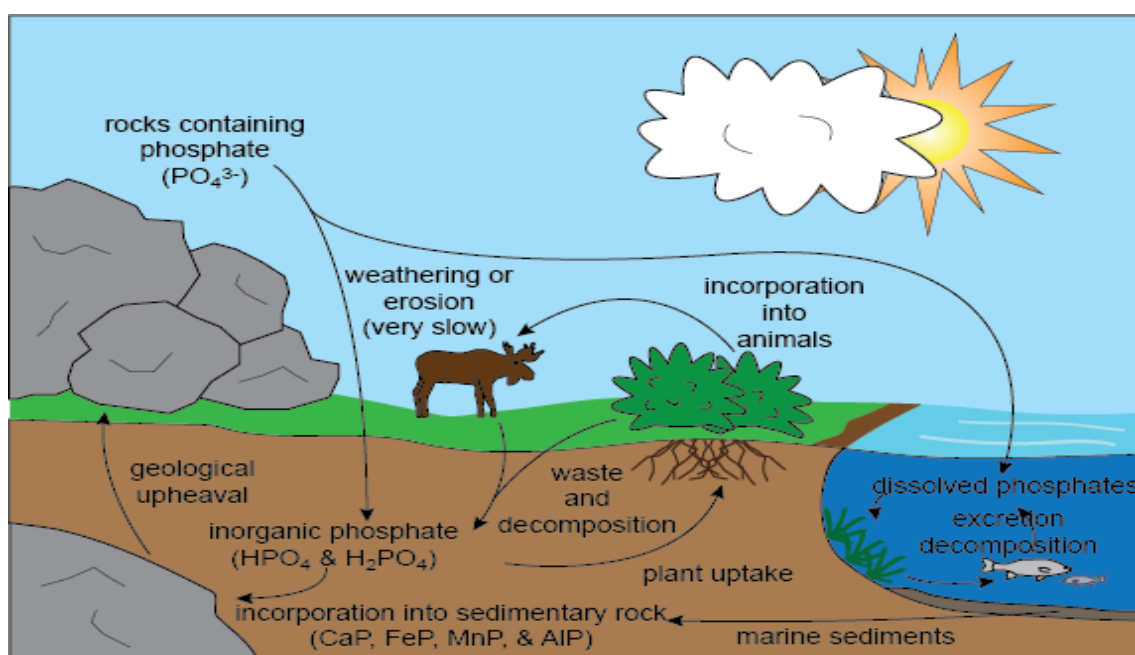


Figure 10. Phosphorus cycle [55]

- Phosphate ions present in the rocks is released by rain and weathering. This inorganic phosphate is then distributed to soil and water resources.
- Phosphate in soil is consumed by the plants and those plants are consumed by animals. Phosphate in plants and animals is incorporated into organic molecules such as DNA. When these plants and animals die, they decompose and release organic phosphate back to soil.
- Organic phosphorus present in the soil cannot be consumed directly by the plants. So, bacteria break down the organic phosphorus to inorganic forms of

phosphorus which can be easily consumed by the plants. This process is known as mineralization.

- Phosphorus in the soil can end up in waterways, for instance, rivers and streams through soil erosion and floods. Phosphorus present in these waterways finally end up in oceans which is incorporated into sediments over time. P cycle have significant impact of human activities. [51]

### Sources of nutrients

Sources of nutrients discharge in the water bodies can be divided into two categories, point source and nonpoint source. The major nonpoint sources of nutrient pollution in the water bodies are excess fertilizers from agricultural land, livestock and pet wastes, forestry, natural background and atmospheric deposition of nutrients. Similarly, point sources of nutrients pollution include sources such as effluent from wastewater treatment plants, industry, and fish farming. [56]

In Finland, nutrients pollution from industries are under control but the nutrient loads coming from agriculture are still significant accounting for up to 80% loads in some place. Municipal wastewater treatment plants have been successful in removing the phosphorus effectively from wastewater but the level of nitrogen removal is still not good. Although the farmers are given agri-environmental subsidies, the concentration of nutrient loads in water is improving slowly. The main reason behind increase in nutrients in the water from the agriculture has been climatic trends such as increase in winter rainfall, frequent snowmelt and shorter duration of snow cover which has caused nutrients to leach from agricultural fields more frequently. [57]

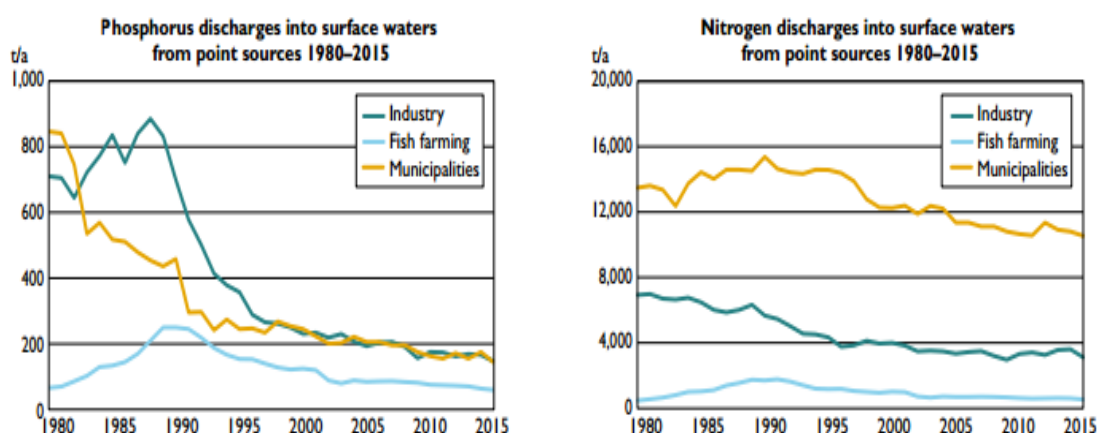


Figure 11. P and N discharges into surface waters from point sources in Finland (1980-2015) [57]

In Figure 11, we can see that the nutrients from point sources, industry and fish farming has been decreasing with time and the limit for the removal of nutrients from wastewater treatment plants set by EU Waste Water Directive has been widely achieved but the nitrogen load in municipal wastewater has not been decreasing significantly.

### **Effect of nutrients**

The main effect of overnutrition in the water bodies is *eutrophication*. It is the excessive growth of plants and algae due to the increase in the nutrients along with other factors, for example, sunlight and CO<sub>2</sub> needed for photosynthesis. Eutrophication can occur naturally over centuries and human activities have increased the rate of eutrophication through different point and nonpoint sources of nutrients loading. This kind of eutrophication caused by an increase in limiting nutrients such as nitrogen and phosphorus is known as *cultural eutrophication*. The consequences of cultural eutrophication are algal blooms, contamination of drinking water and degradation of recreational activities. In US, the cost of damage caused by eutrophication problem alone is approximately \$2.2 billion per year. The main effect of cultural eutrophication in water bodies is formation of toxic and bad smelling phytoplankton that reduce the clarity of water and affect the water quality. Frequent rate of photosynthesis linked to eutrophication can cause depletion of dissolved inorganic carbon and raise the pH to extreme levels during day. Since some organisms depend on perception of dissolved chemical signals for their survival from predators, extreme pH can make them blind. Eutrophication results in algal blooms that limit the penetration of light needed for photosynthesis that reduce the growth of plants and affect predators that need light to catch their prey. When dense algal blooms die, the process of microbial decomposition can use up all the available oxygen in the water creating anoxic or dead zone. Lack of enough dissolved oxygen in the water bodies affect the respiration of plants and aquatic organisms such as fishes and crabs that result in death of those organisms. Some algae are toxic in nature as they produce toxins such as microcystin and anatoxin. Algal blooms have ecological, social and economic impact. Harmful algal blooms can degrade water quality, destruct economically important fisheries, degrade recreation, tourism and pose public health risks in freshwater ecosystems. [58]

Eutrophication has been a problem not only in rivers and lakes but its negative impacts have been seen in marine ecosystem as well. Eutrophication is persistent problem in one of the polluted sea, Baltic Sea. Agriculture is a major source of nutrients such as phosphorus and nitrogen causing eutrophication in Baltic Sea. [59] In Finland, majority



of rivers are in coastal areas that contain excessive amounts of nutrient loads from agricultural land. These rivers finally discharge nutrients into the Baltic Sea, either into the Gulf of Finland or the Gulf of Bothnia. [60] Total discharge of nutrients, phosphorus and nitrogen from Finnish rivers into Baltic Sea from 1970 to 2015 can be seen below in Figure 12.

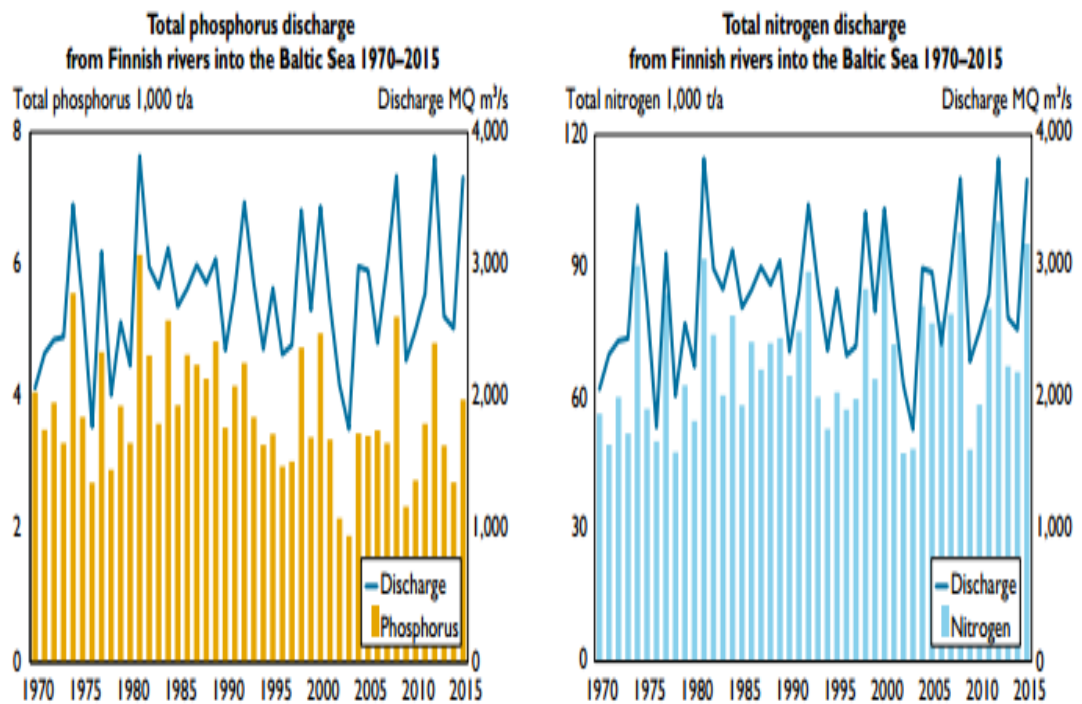


Figure 12. Total P and N discharge from Finnish rivers into Baltic Sea (1979-2015) [57]

Phosphorus and nitrogen load enter the Baltic Sea through rivers, and the amount of load depends on weather conditions and with water volumes in the river. More nutrients get into Baltic Sea during the year with high precipitation than in dry years. We can see that nutrient discharge has increased since 2000 which is because of mild winter conditions where the duration of snow cover is less. In case of nitrogen, mild winters speed up the decomposition of organic material that increase the leaching of organic nitrogen from the soils. [57]

### 3 MATERIALS AND METHODOLOGY

Both onsite measurements and laboratory measurements were performed to determine the values for different parameters of water quality. Water quality parameters such as turbidity, total iron, total nitrogen and total phosphorus were determined through laboratory measurements, whereas parameters such as sample depth, temperature, pH, electrical conductivity and dissolved oxygen were measured onsite using different equipment.

#### 3.1 Sampling sites and conditions

Water samples for laboratory measurements were taken on 17.10.2016 and 18.10.2017 for the streams, Mätäjoki and Haaganpuro, respectively. Five sampling sites were chosen for each stream. Sampling was done by grab methodology where samples were collected only once at a time. From each stream five water samples were collected in five 250 ml plastic bottles from different sites.

Onsite measurements were carried out on the same day of sampling, on 17.10.2016 and 18.10.2017 for Mätäjoki and Haaganpuro respectively. From each sampling sites, onsite measurement was done thrice to obtain the mean value for the parameters.

Different sites, their location and sampling time for both streams can be seen below.

*Table 3. Sampling sites, their location and sampling time for Mätäjoki*

Sites	Sampling Time	Address	Coordinates
M1	13:05	Solkikuja 8, 01600 Vantaa	N 60°15'29.304" E 24°51'44.8308"
M2	13:43	Gamla Nurminjärvivägen 3, 00420 Helsinki	N 60°15'8.4348" E 24°52'6.4704"
M3	14:30	Fagottipolku 2, 00420 Helsinki	N 60°14'24.072" E 24°51'49.392"
M4	14:51	Trumpettipolun kevyen liikenteen silta, 00420 Helsinki	N 60°14'16.0692" E 24°51'56.7972"
M5	15:13	Mätäjoen kevyenliikenteen silta, 00440, Helsinki	N 60°14'5.0892" E 24°51'59.8752"





Figure 13. Sampling sites of Mätäjoki

Table 4. Sampling sites, their location and sampling time for Haaganpuro

Sites	Sampling Time	Address	Coordinates
H1	11:50	Hämeenlinnanväylä, 00101, Helsinki	N 60°12'42.894" E 24°54'2.1492"
H2	12:15	Hämeenlinnanväylä, 00101, Helsinki	N 60°12'34.6428" E 24°53'52.1016"
H3	12:41	Kytösuon kevyen liikenteen silta, 00300, Helsinki	N 60°12'24.6816" E 24°53'38.3496"
H4	13:05	Rymättylänpolku 2, 00300, Helsinki	N 60°12'14.76" E 24°53'32.7588"
H5	13:26	Tilkantorin kevyen liikenteen silta, 00300, Helsinki	N 60°12'10.1844" E 24°53'30.9876"



Figure 14. Sampling sites of Haaganpuro

### 3.1.1 Weather

The surrounding temperature was around 6-7 degree Celsius on both days, 17.10.2017 and 18.10.2017 during onsite measurements and sampling. In the first sampling day, there was intermittent clouds, whereas second day was partly sunny. Probability of precipitation was 0%, humidity was 76% and cloud cover was 69% on first day of sampling, whereas in second day of sampling it was 1%, 72% and 65% respectively.

### 3.1.2 Equipment used

The equipment used during sampling and onsite measurements are as follows:

- Sampling bottles
- Sample collector
- Depth measuring rod
- pH and conductivity meter (SevenGo Duo™)
- DO meter (HQ40d)

### 3.1.3 Sampling procedures

Following procedures were applied before and during sampling:

- Before going to sampling sites, all the necessary equipment needed for sampling were collected.
- Proper labeling of sampling bottles was done.
- Sample was collected directly from the sampling bottles except in some deep sampling site, sample collector was used from the bridge to collect the sample.
- Sample bottles were rinsed more than 3 times before taking the sample.
- Samples were collected especially from the middle part of the stream where there was a good flow.
- Lid of the sample bottles were closed air tight immediately after filling with water sample to protect the sample from contaminations.
- After sample collection, sample bottles were kept in the refrigerator in Chemistry laboratory of Metropolia UAS for preservation.
- Those samples were later used for the laboratory analysis.

## 3.2 Onsite measurements

### 3.2.1 Procedures

Before onsite measurements all necessary equipment were collected and different other procedures were applied during onsite measurements which are as follows:

#### Sample depth

Depth of water was measured from the place where the sample was taken. Water depth was measured using measuring rod. In the small water streams, depth was measured easily, whereas in the deeper sampling site, measuring rod was used from the bridge.

#### pH and electrical conductivity

pH and electrical conductivity were measured using the pH meter. Before using the available pH meter, it was first calibrated. For the calibration of the pH meter, 3-point calibration was done with following steps:

- First, pH mode was selected and the electrode was rinsed with deionized water and was dried using tissue paper.
- Electrode was then placed into the buffer solution of pH 4.01 and button 'Cal' was pressed and finally button 'read' was pressed that displayed the buffer value 4.01.
- Similarly, the electrode was rinsed again with deionized water and was dried. Then it was placed in next calibration buffer solution of pH 7 and button 'Cal' was pressed and finally button 'read' was pressed that displayed the buffer value 7.
- As a last step, same above step was repeated using the buffer solution of 9.21.

Similarly, calibrated conductivity meter was used to measure the electrical conductivity of water samples. During onsite measurements, pH/conductivity meter was dipped into the water and button read was pressed and waited until the stable value was obtained on the screen of pH/conductivity meter. The obtained stable values for pH and conductivity were noted. Before every new measurement, probe of pH/conductivity meter were rinsed properly.

### **Dissolved oxygen and temperature**

Dissolved oxygen (DO) and temperature were measured using a DO meter, HQ40d. The measurement range of this equipment is 0.01-20 mg/l. The DO meter available in the Environmental Engineering laboratory of Metropolia UAS was already calibrated. During onsite measurements, the DO meter was dipped into the water and the Read button was pressed. When the measurement was stable, a lock icon was shown on the screen. The stable values of DO and temperature were noted down. For every new measurement, the probe of DO meter was rinsed properly.

## **3.3 Laboratory measurements**

Laboratory measurements were carried out in the Environmental Engineering laboratory of Metropolia UAS. Equipment used and procedures applied during laboratory works are as follows:

### **3.3.1 Equipment used**

Equipment used during laboratory measurements are the following:

- Hanna HI 88713- ISO Turbidity meter
- Hach/Lange Spectrophotometer DR 3900



- Hach/Lange LT200 Thermostat
- Microwave Plasma – Atomic Emission Spectroscopy (4100 MP-AES)
- Round bottom flasks of different sizes
- Beakers
- Filter Papers
- Pipette

### 3.3.2 Chemicals used

Chemicals used during laboratory measurements are listed below:

- Reagents used in analysis of nitrogen and phosphorus (LCK 138 and LCK 349)
- ( $\text{Fe}^{2+}$  200 mg/l + 2 ml 2.5 M  $\text{H}_2\text{SO}_4$ ) solution

### 3.3.3 Procedures

Procedures used for different laboratory measurements are explained in the following paragraphs.

#### **Turbidity**

Turbidity was measured using turbidity meter in Environmental Engineering lab. When taking the measurements, cuvettes without any scratches were used to prevent inaccurate readings. Around 10 ml of water sample was filled in the dry and clean cuvettes and were properly capped to prevent spillage of water samples. Cuvette was wiped with lint-free cloth adding few drops of silicon oil to obtain accurate readings. Then the sample containing cuvette was placed into the turbidity meter and the lid was closed. 'Read' button was pressed to obtain the value of turbidity in selected units. Obtained values were noted down for analysis.

#### **Total iron**

Total iron concentration of water samples was measured using Agilent 4100 MP-AES. In the beginning, colorimetric analysis was chosen to determine the iron concentration in the water samples which is based on the change in the intensity of color of solutions with variations in concentrations. But even with adding reagents, hydroxylamine hydrochloro-

ride and o-phenanthroline solution, samples did not show any color as they were supposed to like the standard solutions with concentrations 0.5 to 5 mg/l. Hydroxylamine hydrochloride is a reducing agent that takes iron present in the solution from 3+ oxidation state down to 2+ oxidation state and o-phenanthroline is a reagent that react with iron in 2+ oxidation state to form a color complex. No change in color, proved that the concentration of iron in the water sample was very low below 0.5 mg/l.

To find out the exact concentration of iron in the water samples, even the concentration was below 0.5 mg/l, 4100 MP-AES technology was used. 4100 MP-AES uses microwave plasma and an atomic emission spectroscopy detector which is a new and enhanced technology in the field of environmental monitoring and analysis. MP-AES is similar to Induced Couple Plasma – Atomic Emission Spectroscopy (ICP-AES) as they both measure and analyze spectra by an atomic emission spectrometer (AES) using concentration-intensity correlations which are similar to how Beer-Lambert law applies to atomic absorption spectroscopy (AAS). [61]

The difference between MP-AES and ICP-AES is the way how the plasma is formed. 4100 MP-AES uses nitrogen based plasma that runs on air using N<sub>2</sub> generator, that gives strong plasma and conventional torch. Nitrogen based plasma reaches temperature of approximately 5000 K. At such a temperature, atomic emission is strong producing excellent detection limits. [62] Instrument uses atomic emission detection at predefined wavelength. [63] It has higher improved performance than flame atomic absorption (AA). It is cost effective since it runs on air, there is no need of expensive gas such as argon. It is easy to use and has improved safety as it eliminates use of flammable gases. [64]

#### **Working principle of MP-AES**

Inside MP-AES instrument, plasma is formed in a conventional torch using nitrogen gas. This formed plasma is a high temperature excitation source which is ideal for the sample atomization and excitation producing high intensity emission lines. First, aerosols formed from sample using nebulizer and spray-chamber goes into the plasma where they are dried, decomposed and atomized. Once an atom is excited it emits light in a characteristic pattern of wavelengths (emission spectrum) as it returns to the lower energy states. Emission from the plasma is then directed into fast scanning monochromator. The selected wavelength range is imaged onto the high efficiency CCD detector that measures both spectra and background simultaneously for optical precision. MP-AES then measure the quantity of concentration of an element in a sample by comparing its emission to that of known concentrations of the element which is plotted on a calibration curve. The final result obtained is the concentration of element in the sample. [62]



Figure 15. Iron test using 4100 MP-AES technology

#### Preparation and measurement of standard solutions and unknown samples

Six standard solutions of concentrations ( $M_2$ ), 0.05, 0.15, 0.25, 0.35, 0.45 and 0.50 ppm were prepared using available ( $\text{Fe}^{2+}$  200 mg/l + 2 ml 2.5 M  $\text{H}_2\text{SO}_4$ ) mother solution. Dilution of mother solution was done in such a way that volume of solution to be pipette lies in between 0.5 ml to 5 ml to prepare standard solutions. Therefore, for the dilution, 5 ml of mother solution was added to a flask of 100 ml ( $V_2$ ), which was then filled with deionized water till the mark. The concentration of the mother solution ( $M_1$ ) became 10 ppm. The volume of mother solution ( $V_1$ ) to be pipetted in six different 100 ml flasks, was calculated as 0.5, 1.5, 2.5, 3.5, 4.5 and 5 ml, using the formula,  $M_1 \cdot V_1 = M_2 \cdot V_2$ . After pipetting respective volume of solutions, flasks were filled with deionized water till the mark. In this way six standard solution of known concentrations were prepared to make the calibration curve.

Ten unknown samples of ten different sites of two streams were first filtered using filter paper to remove the suspended solid particles in the water sample. 50 ml of each filtered samples were put into flasks for the measurement.

After preparing standard solutions and unknown samples, calibration curve was plotted using known concentrations of standard solutions in the computer connected with MP-AES machine. Then unknown samples were measured one by one using MP-AES. Finally, the concentrations of all unknown samples were obtained in the computer.

## Nitrogen and phosphorus

Total nitrogen and phosphorus were measured using Hach/Lange Spectrophotometer DR 3900 (Figure 16). DR 3900 is UV/Visible spectrophotometer with a wavelength of 320-1100 nm. It works on the principle that the concentration of the substances to be analyzed is determined when the light is absorbed by the sample at the certain wavelength. It is one of the easiest way to perform test for the water analysis that provides digital readouts in the units of concentration, absorbance or percent transmittance. Nitrogen and phosphorus test have separate ways of preparing sample. [65]

Water samples were taken out from the refrigerator and all the necessary kits were made ready for the evaluation of total nitrogen and phosphorus in the water samples. The sample preparation and measurement procedure for total nitrogen and total phosphorus are explained, respectively, in the following paragraphs.



Figure 16. Nitrogen and phosphorus test using Hach/Lange Spectrophotometer DR 3900

Datasheet of product LCK138 was used to follow the procedures of sample preparation and measurement for total nitrogen in the sample. The measuring range is 1-16 mg/L TN<sub>b</sub>. First, 1.3 ml of the water sample, 1.3 ml of the solution Reagent A and 1 tablet of Reagent B were added in quick succession to a dry reaction tube and it was closed immediately without inverting. Then, the reaction tube was heated immediately at the temperature of 100 °C for 60 minutes in the thermostat. After that, it was cooled down, and 1 MicroCap of reagent C was added. The reaction tube was closed and inverted a



few times until the freeze-dried contents were fully removed from the MicroCap C and all streaks were vanished. Next, 0.5 ml of digested sample was pipetted slowly into the cuvette test, after which 0.2 ml of Solution D was slowly pipetted in the cuvette and it was immediately closed and inverted a few times until no more streaks were seen. Finally, after 15 minutes, the outside part of cuvette was cleaned thoroughly, and the cuvette was inserted in DR 3900 spectrophotometer to evaluate the concentration of nitrogen in the sample.

Datasheet of product LCK349 was used to follow the procedures of sample preparation and measurement for total Phosphorus in sample. The measuring range is 0.05-1.5 mg/l  $\text{PO}_4\text{-4}$ . First, the foil was removed carefully from the screwed-on DosiCap Zip. DosiCap Zip was unscrewed and 2.0 ml of sample was pipetted into the cuvette. DosiCap Zip was then screwed back tightly keeping the fluting at the top. The cuvette was shaken firmly back and forth 2 to 3 times. Next, it was heated in the thermostat at the temperature of 100 °C for around 60 minutes. It was allowed to cool at room temperature and was shaken firmly. After that, 0.2 ml of Reagent B was pipetted into the cooled cuvette. Reagent B was closed immediately after use. Grey DosiCap C was then screwed onto the cuvette and it was inverted few times. The cuvette was left in room temperature for 10 minutes and was inverted few times more. Finally, the outer part of the cuvette was cleaned thoroughly, and the cuvette was inserted in DR 3900 spectrophotometer to evaluate the concentration of phosphorus in the sample.

### 3.4 Safety precautions

Safety measures were applied while performing water sampling, onsite measurements and laboratory analysis. During water sampling and onsite measurements, priority was given to safety measures such as use of gloves, proper clothes and shoes. In the larger and deeper sampling sites, sample was taken from the bridge using a water sample collector.

In the laboratory measurements, priority was given to chemical safety. Chemical reagents used in iron, nitrogen and phosphorus measurements are corrosive, hazardous to health, irritating and poisonous. Therefore, safety measures such as wearing gloves, lab coats and safety glasses were applied to protect skin and eyes. Safety data sheet of reagents of products LCK 138 and LCK 349 were read before handling any chemicals during laboratory works.

## 4 RESULTS

The results of parameters obtained from different onsite measurements and laboratory measurements of the streams Mätäjoki and Haaganpuro are presented in two sections labeled according to the names of the streams.

### 4.1 Mätäjoki

The results obtained from onsite measurements for stream Mätäjoki were as follows:

*Table 5. Results of onsite measurements of Mätäjoki*

Samples	Sample Depth (cm)	pH	Conductivity ( $\mu\text{S}/\text{cm}$ )	Temperature ( $^{\circ}\text{C}$ )	Dissolved Oxygen (mg/l)	Oxygen Saturation (%)
M1	46	6.93	322	7.1	2.01	16.2
		6.98	365	6.9	1.57	13.0
		7.06	329	6.9	1.41	11.3
M2	16	7.14	325	6.0	2.91	22.8
		7.17	332	6.1	2.36	18.5
		7.19	331	6.1	2.69	21.1
M3	80	7.35	370	5.7	8.60	66.8
		7.56	373	5.5	8.84	68.3
		7.50	371	6.0	8.46	66.2
M4	35	7.51	341	5.5	7.20	55.6
		7.47	346	5.6	7.02	54.2
		7.49	348	5.5	6.93	53.5
M5	31.5	7.59	338	5.9	6.63	51.7
		7.66	346	5.7	6.77	52.6
		7.65	249	5.6	6.99	54.2

In Mätäjoki, sampling and onsite measurements were done from the sites having water depth between 0.1 to 0.8 m. Three measurements were done for different parameters from each sampling sites. The average water temperature of the stream was 6.0 °C with pH in the range of 7 to 8. The concentration of DO varied from 1 to 9 mg/l with average oxygen saturation of 40%. Sampling sites, M1 and M2 had very low level of DO in comparison to other sites. The average electrical conductivity of stream was around 340 µS/cm.

The results obtained from laboratory measurements were as follows:

*Table 6. Results of laboratory measurements of Mätäjoki*

Site	N <sub>Total</sub> (mg/l)	P <sub>Total</sub> (mg/l)	Fe <sub>Total</sub> (mg/l)	Turbidity (NTU)
M1	1.17	0.080	0.36	5.51
M2	1.31	0.095	0.33	6.06
M3	1.31	0.045 *	0.33	6.36
M4	1.45	0.075	0.43	5.97
M5	1.29	0.059	0.32 *	6.77

In Mätäjoki the concentration of total nitrogen and phosphorus was very low. The average total nitrogen concentration in the stream was 1.3 mg/l, whereas the average concentration of total phosphorus was 0.07 mg/l. In site M3, the concentration of total phosphorus was below the measuring range as the total phosphorus was measured in the range of 0.05-1.5 mg/l.

The average total iron in the stream was 0.35 mg/l. In site M5, the actual concentration of total iron was 0.64 mg/l which was out of measuring range; thus, it was diluted by a dilution factor of 2, to get the value within the measuring range. The average turbidity of Mätäjoki was 6.0 NTU.

## 4.2 Haaganpuro

The results obtained from onsite measurements for stream Haaganpuro were as follows:

Table 7. Results of onsite measurements of Haaganpuro

Samples	Sample Depth (cm)	pH	Conductivity ( $\mu\text{S/cm}$ )	Temperature ( $^{\circ}\text{C}$ )	Dissolved Oxygen (mg/l)	Oxygen Saturation (%)
H1	17	7.42	388	7.3	10.81	87.9
		7.61	395	7.0	10.97	88.4
		7.70	396	6.8	10.96	87.9
H2	42	7.51	403	7.3	10.41	85.0
		7.61	408	7.1	10.49	84.7
		7.67	409	7.0	10.51	84.7
H3	26	7.58	404	7.3	9.70	78.9
		7.63	411	7.1	9.86	79.7
		7.69	412	7.1	9.87	79.8
H4	28	7.76	416	6.8	8.01	64.2
		7.73	422	6.5	8.03	63.9
		7.72	425	6.5	8.02	63.8
H5	30	7.70	406	6.8	8.57	68.6
		7.69	411	6.6	8.61	68.7
		7.67	413	6.5	8.43	67.1

In Haaganpuro, sampling and onsite measurements were done from the sites having water depth between 0.1 to 0.42 m. Three measurements were done for different parameters from each sampling sites. The average water temperature of the stream was 7.0  $^{\circ}\text{C}$  with average pH of 7.6. The concentration of DO varied from 8 to 11 mg/l with average oxygen saturation of 77%. All the sampling sites had similar concentrations of DO. The average electrical conductivity of the stream was around 408  $\mu\text{S/cm}$ .

The results obtained from laboratory measurements were as follows:

Table 8. Results of laboratory measurements of Haaganpuro

Site	N <sub>Total</sub> (mg/l)	P <sub>Total</sub> (mg/l)	Fe <sub>Total</sub> (mg/l)	Turbidity (NTU)
H1	0.61	0.037 *	0.33	6.10
H2	1.46	0.017 *	0.28	7.24
H3	0.58	0.033 *	0.24	5.90
H4	1.55	0.037 *	0.19	8.67
H5	1.07	0.044 *	0.29	6.30

In Haaganpuro, the concentration of total nitrogen and phosphorus was very low. The average total nitrogen concentration in the stream was 1.05 mg/l, whereas the average concentration of total phosphorus was 0.03 mg/l. The concentration of total nitrogen in the sites H1 and H3 was under the measuring range, whereas the concentration of total phosphorus in all the sites was under the measuring range as the total phosphorus was measured in the range of 0.05-1.5 mg/l. The average total iron concentration and average turbidity in the stream was 0.27 mg/l and 6.0 NTU respectively.

## 5 DISCUSSION

This section discusses the results of water quality parameters for the streams, Mätäjoki and Haaganpuro obtained from both onsite measurements and laboratory evaluations.

### 5.1 Mätäjoki VS Haaganpuro

The water quality of Mätäjoki seems good based on the chosen physio-chemical parameters and sampling season. pH of water in Mätäjoki during autumn 2016 was in the range suitable for the aquatic life, since the normal range of pH in freshwaters is 6.5 to 9. The water temperature of Mätäjoki is in the optimal range needed for trout. The minimum concentration of DO in streams to support large species of fishes is 4 mg/l. Result shows that sites M1 and M2 have very low level of DO which is below the minimum level needed for aquatic life. The main reason behind the low level of DO in these sites can be over growth of plant species, bacteria and excess DO that consume more oxygen and the

increase in the number of cloudy days that make respiring plants to use more oxygen because of no photosynthesis. [23] Mätäjoki has an optimum electrical conductivity that lies in the range of 150-500  $\mu\text{S}/\text{cm}$  that support the diverse aquatic life. [66] The turbidity level in Mätäjoki is below 7 NTU, which shows that it does not have any effect on aquatic life, especially trout. The acceptable range of turbidity for trout streams is less than 10 NTU. [67] The level of nutrients and iron concentration seems fine in Mätäjoki. For rivers and streams to be eutrophic, the suggested limit of total nitrogen is  $>1.5 \text{ mg}/\text{l}$ , whereas for total phosphorus it is  $>0.075 \text{ mg}/\text{l}$ . Both nutrients in Mätäjoki are within the limit; however, the concentration of total phosphorus seems very close to the limit value that can cause eutrophication in the stream. The main source of phosphorus in the streams, for example, Mätäjoki in Finland is agricultural discharge and effluent from the paper and pulp industries. [68]

The quality of water in Haaganpuro also seems pretty fine based on chosen water quality parameters and sampling season. Water temperature, pH, conductivity, DO and turbidity level of Haaganpuro is in the range that supports aquatic life. Similarly, the results show that the concentrations of nutrients and total iron in the water is very low.

The quality of water in both streams are good and within the standard limits, but if we compare the water quality of these streams, Haaganpuro is little better than Mätäjoki. They are similar in terms of water temperature, pH, conductivity, and turbidity. The level of DO in Haaganpuro is far better than in Mätäjoki that means aquatic life is better in Haaganpuro. Similarly, in terms of nutrients and total iron concentration, Haaganpuro seems better.

## 5.2 Water quality of Mätäjoki (1995-2016)

Water quality monitoring of Mätäjoki started from 1987 by Environmental Center, city of Helsinki. Water quality of Mätäjoki was studied in detail by Olli Ruth in the year 1995-1996 where the samples were taken at weekly intervals. Precipitation during the monitoring period was less than normal which was about 85% of a normal year and its flow into the bay of Iso-Huopalahti was 140 l/s. The average water temperature during the year was  $6.4 \text{ }^\circ\text{C}$ . During the year, the median water pH at various sampling points was 7.1. The water quality of Mätäjoki was in better condition than in mid 1970s. [4]

In 2004, water quality of Mätäjoki was monitored along with other 21 urban streams in Helsinki by Vuokko Tarvainen. The average water temperature of the stream was  $7.12 \text{ }^\circ\text{C}$ . The pH of the runoff water was on average of 7.18. The average saturation rate for

the whole brook was 64%. Regarding other variables, there were no special problems with water quality. [69]

Results from onsite and laboratory measurements of 2016 show that there are changes in water quality parameters in Mätäjoki from 1995 to 2016 (Figure 17, Figure 18 and Figure 19).

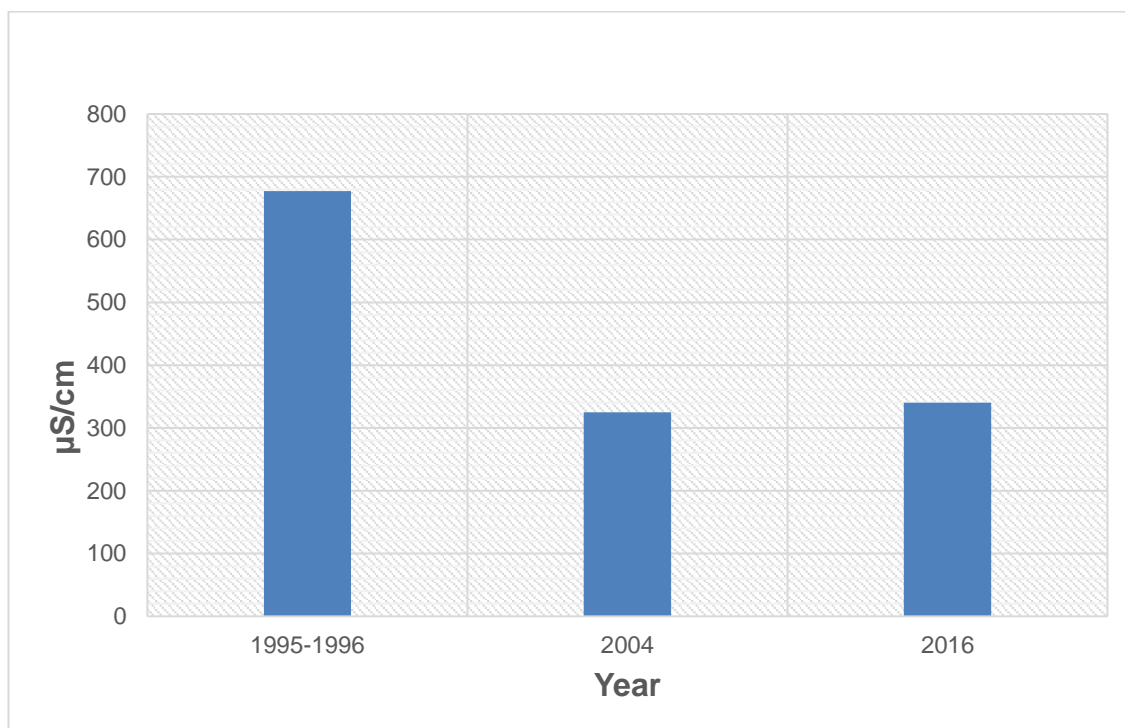


Figure 17. Electrical conductivity in Mätäjoki (1995-2016)

The electrical conductivity of the various sampling points in the runway varied very much in the same way as the dissolved substance concentration in 1995-1996. Conductivity was smallest in the upper stream at Vantaa and increased in the lower stream near the sea. The average conductivity of all sampling points was 677 µS/cm. [4] The conductivity of Mätäjoki in 2004 was in the range of 139 to 683 µS/cm. [69] In Figure 17, we can see that the conductivity of Mätäjoki in 2016 has decreased by almost half than in 1995-1196 and is slightly higher than it was in 2004.

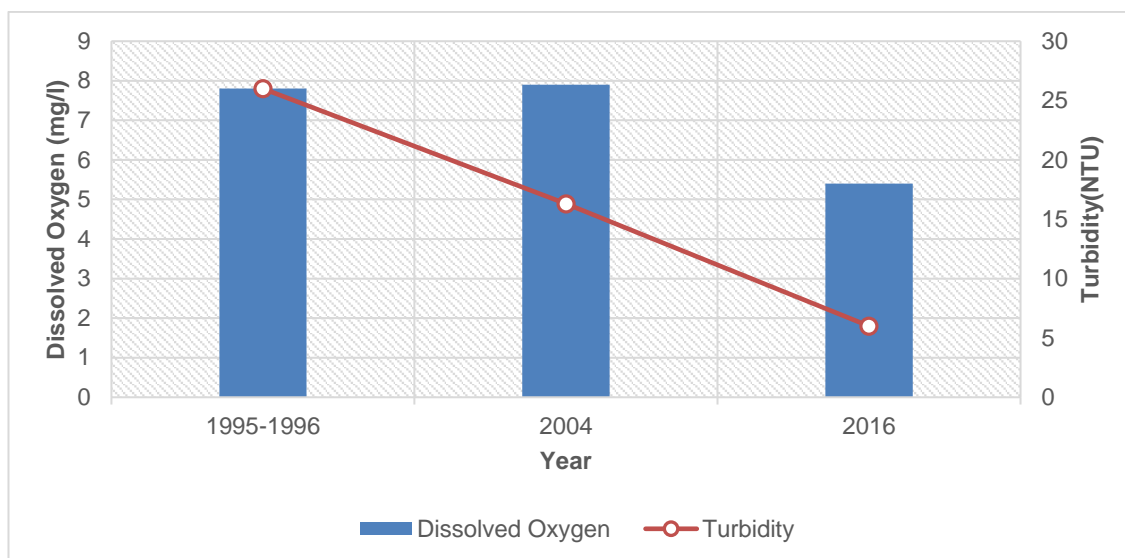


Figure 18. DO and turbidity level in Mätäjoki (1995-2016)

The oxygen content of the water fluctuated from 0.1 mg/l to 14.1 mg/l during the year 1995-1996 from samples collected at different sampling points. Oxygen saturation in the stream varied from 1-97 % during individual observations. The average oxygen saturation was 61 % and average turbidity was 26 FTU. [4] In 2004, concentration of dissolved oxygen varied from 2.41 to 13.25 mg/l and turbidity was in the range of 4.8-36 NTU. [69] Change in the concentration of dissolved oxygen and the level of turbidity from 1995-1996 to 2016 can be seen in Figure 18. Level of DO is low in Mätäjoki in 2016 than it was in 1995-1996 and 2004, and the turbidity level is excellent in 2016 in comparison to years, 1995-1996 and 2004 (Figure 18).

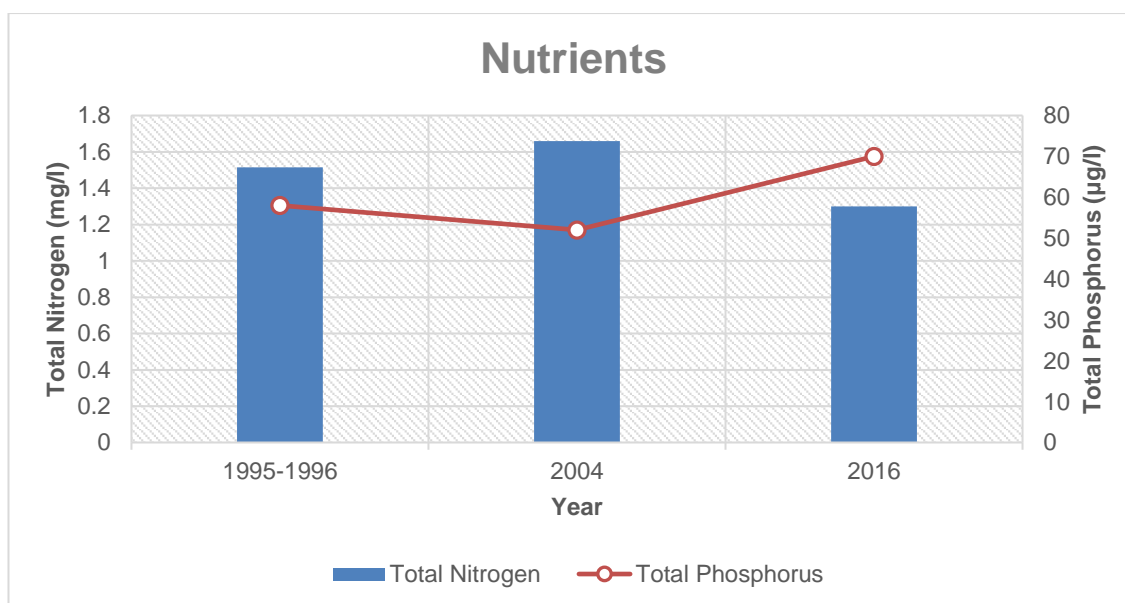


Figure 19. Total N and Total P concentration in Mätäjoki (1995-2016)



In 1995-1996, total nitrogen concentration varied from 0.92 to 3.8 mg/l and total phosphorus varied from 0.017 to 0.13 mg/l. On average, 50% of total nitrogen was  $\text{NO}_3$ , 22.5% was  $\text{NH}_4$  and 1.2% was  $\text{NO}_2$ . [4] Similarly, in 2004 the concentration of total nitrogen was in the range of 0.57 to 3.3 mg/l and total phosphorus was in the range of 0.014 to 0.095 mg/l. [69] Change in the average concentration of both nutrients from 1995-1996 to 2016 can be seen in Figure 19. Total nitrogen in Mätäjoki has decreased in 2016, whereas total phosphorus has increased (Figure 19).

The concentration of total iron in Mätäjoki is better than it was in 1995-1996. In the year 1995-1996, water contained an average of 1.4mg/l of iron in the entire stream. Between 1979 and 1989, samples taken at various runoffs contain an average of 2.6 mg/l of iron. [4] Present total iron concentration in Mätäjoki which is below 0.4 mg/l shows that concentration of iron in the stream is in better condition.

### **5.3 Water quality of Haaganpuro (1987-2016)**

Water quality monitoring of Haaganpuro started from 1987 by Environmental Center, city of Helsinki. Two annual water samples from summer and autumn were taken from Haaganpuro to monitor the water quality. The average water temperature between July and October was 10.8 °C with average pH of 7.35. [70]

According to the water quality monitoring done by Vuokko Tarvainen in 2004, the water quality of Haaganpuro was fairly good. The average water temperature was 6.6 °C with average pH 7.29. [69]

Results from onsite and laboratory measurements of 2016 show that there are changes in water quality parameters in Haaganpuro from 1987 to 2016 (Figure 20, Figure 21 and Figure 22).

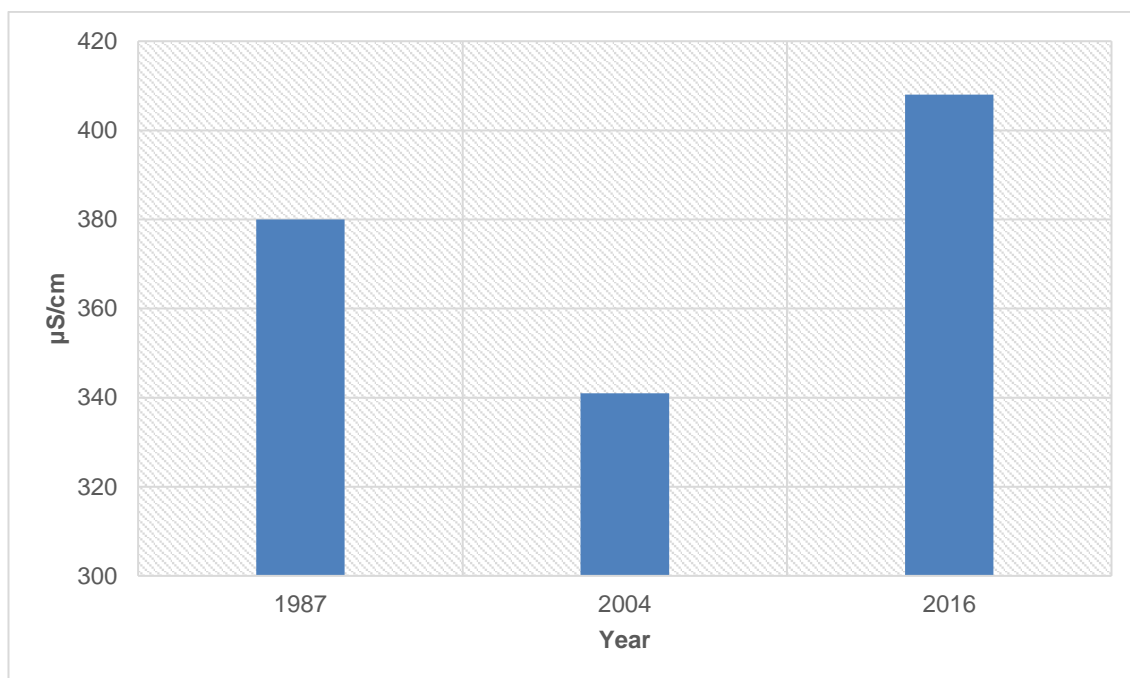


Figure 20. Electrical conductivity in Haaganpuro (1987-2016)

In Figure 20, we can see that the average conductivity of Haaganpuro in 2016 is greater than it was in 1987 and 2004. Conductivity was least in the year 2004 in comparison to 1987 and 2016.

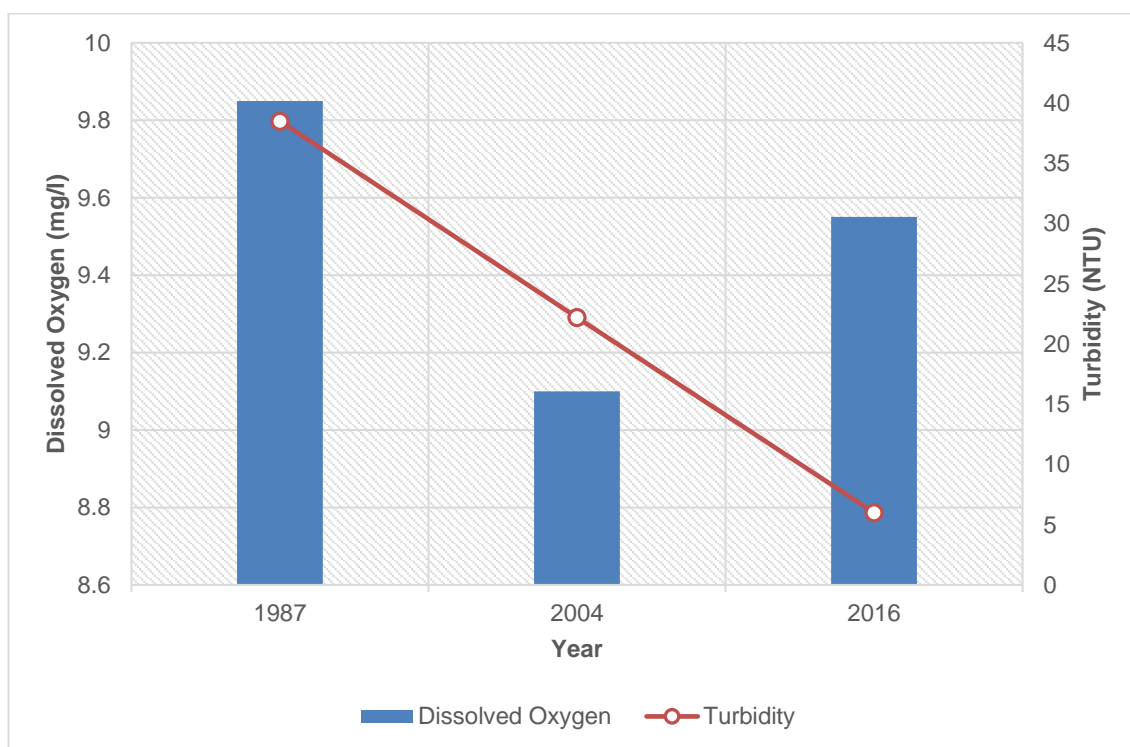


Figure 21. DO and turbidity level in Haaganpuro (1987-2016)

In 1987, DO in Haaganpuro was 9.0 mg/l in the month of July and 10.7 mg/l in October. The average oxygen saturation was 86.5 %. [70] In 2004, Haaganpuro had average oxygen saturation of 73.3%. [69] Turbidity level was higher in 1987 than in the year 2004. Change in the concentration of dissolved oxygen and the level of turbidity from 1987 to 2016 can be seen in Figure 21. The level of DO in Haaganpuro in 2016 is greater than it was in 2004 and the level of turbidity has decreased significantly from 1987 to 2016 (Figure 21).

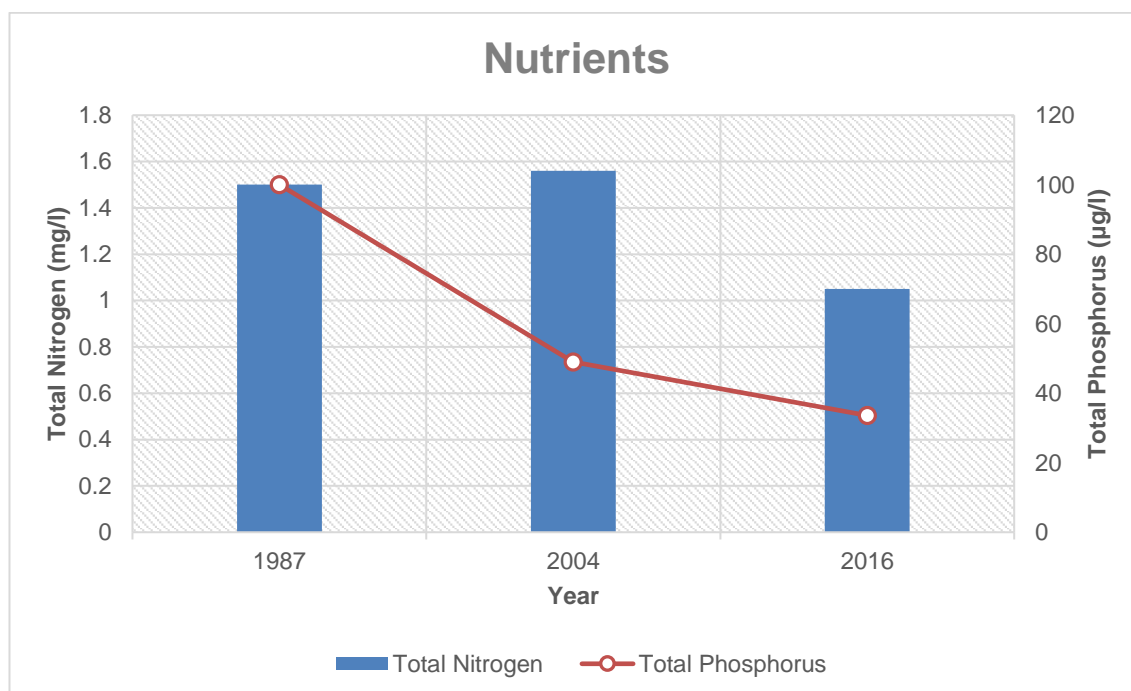


Figure 22. Total N and Total P concentration in Haaganpuro (1987-2016)

In 1987 the concentration of total nitrogen was 1.6 mg/l in the month of July and it was 1.4 mg/l in October. The concentration of total phosphorus was found to be same in July and October. [70] In 2004, total nitrogen was in the range of 0.83 to 2.2 mg/l, whereas total phosphorus was in the range of 11 to 118 µg/l. [69] The change in the average concentration of both nutrients from 1987 to 2016 can be seen in Figure 22. Concentration of both total nitrogen and total phosphorus in Haaganpuro is better in 2016 than in 1987 and 2004.

The concentration of total iron in Haaganpuro is better than it was in 1987. In the year 1987, water contained an average of 3.0 mg/l of iron in the stream. [70] The average concentration of total iron was found to be 2.85 mg/l in 2004. [69] Present total iron concentration in Haaganpuro which is below 0.3 mg/l shows that concentration of iron in the stream has decreased drastically.

## 6 CONCLUSION

The main goal of this thesis was to study the quality of water in urban streams, Mätäjoki and Haaganpuro. Results of onsite measurements and laboratory measurements show that the water quality in both streams is in good condition. Almost all the water quality parameters are within the limit to support the aquatic life in these streams. The comparison of water quality parameters of these streams clearly shows that Haaganpuro is in better condition than Mätäjoki. The problem found in the Mätäjoki is that, the concentration of dissolved oxygen in the first two sampling sites was too low to support aquatic life. The average concentration of total phosphorus in Mätäjoki was found to be very close to limit value that can support algal bloom in the stream.

Water quality of both Mätäjoki and Haaganpuro has been monitored for a long time. Comparing three different years of data, water quality in both streams is in better condition than it was in the past. Turbidity and total iron concentration has decreased significantly in both streams. Currently, total nitrogen in both streams is seen low than it was in the past. Only the total phosphorus concentration has increased in Mätäjoki in comparison to past data, whereas in case of Haaganpuro, total phosphorus has decreased.

In general, therefore, it seems that sampling sites M1 and M2 of Mätäjoki having very low DO have possibility that they have excess plants and bacteria that consume the oxygen in the water. High concentration of total phosphorus in Mätäjoki suggests that sources such as agriculture, pulp and paper industries and wastewater treatment plants are still contributing phosphorus in the stream to some level. To maintain the good water quality of these streams, it is important to reduce pollutants and nutrients loading from both point and nonpoint sources.

This thesis provides the latest knowledge on the current situation of water quality in Mätäjoki and Haaganpuro based on chosen parameters. A limitation of this study is that samples were collected from only five sampling points for each stream and that they were collected in a single day for each stream. More regular monitoring is needed to determine the clear trend of water quality in these urban streams.

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## Appendices

### Appendix A: Method settings during iron test using Agilent 4100 MP-AES technology

METROPOLIA AMMATTIKORKEAKOULU  
KEMIAN LABORATORIO

Shree iron test.mpsw

Method Settings:

Element	Wavelength (nm)	Label	Type	Background Correction	Calibration Fit
Fe	259.940	Fe	Analyte	Auto	Linear Weighted

Replicates: 3  
Rinse time (s): N/A

Calibration Correlation Coefficient Limit: 0.95  
Rinse time fast pump: N/A

Pump Speed (rpm): 15  
Air Injection Mode: Off

Blank Subtraction: On  
Standard addition: Off

Sample introduction: Manual  
Reagent Blank: Off

Stabilization time (s): 15  
QC Active: Off

Sample Uptake Time (s): 15  
Reslope: Off

Sample uptake fast pump: On

Settings per element:

Label (Wavelength nm)	Type	Read Time (s)	Viewing position	Nebulizer Pressure (kPa)
Fe (259.940)	Analyte	3	0	240

Calibration parameters:

Label (Wavelength nm)	Minimum Concentration	Maximum Concentration	Calibration Error
Fe (259.940)	0 mg/L	0.55 mg/L	5 %

Sequence table:

Sample Label	Weight (g)	Volume (mL)	Dilution
H1	1.0	1.0	1.0
H2	1.0	1.0	1.0
H3	1.0	1.0	1.0
H4	1.0	1.0	1.0
H5	1.0	1.0	1.0
M1	1.0	1.0	1.0
M2	1.0	1.0	1.0
M3	1.0	1.0	1.0
M4	1.0	1.0	1.0
M5	1.0	1.0	1.0

1 of 2

## Appendix B: Results obtained during iron test using Agilent 4100 MP-AES technology

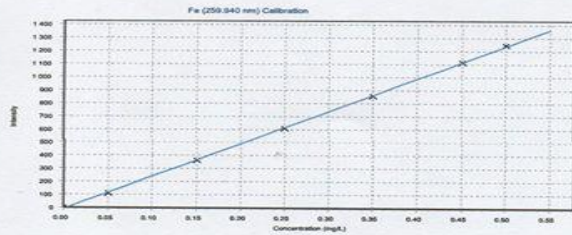
METROPOLIA AMMATTIKORKEAKOULU  
KEMIAN LABORATORIO

Shree iron test.mpws

Results:

Label	Date Time	Element Label (nm)	Concentration	Unit	SD	%RSD
Blank	9.11.2016 09:08:38	Fe (259.940 nm)	0.00	mg/L	N/A	N/A
Standard 1	9.11.2016 09:09:59	Fe (259.940 nm)	0.05	mg/L	N/A	N/A
Standard 2	9.11.2016 09:11:14	Fe (259.940 nm)	0.15	mg/L	N/A	N/A
Standard 3	9.11.2016 09:12:59	Fe (259.940 nm)	0.25	mg/L	N/A	N/A
Standard 4	9.11.2016 09:13:58	Fe (259.940 nm)	0.35	mg/L	N/A	N/A
Standard 5	9.11.2016 09:15:11	Fe (259.940 nm)	0.45	mg/L	N/A	N/A
Standard 6	9.11.2016 09:16:14	Fe (259.940 nm)	0.50	mg/L	N/A	N/A
H1	9.11.2016 09:17:37	Fe (259.940 nm)	0.33	mg/L	0.01	1.85
H2	9.11.2016 09:18:59	Fe (259.940 nm)	0.28	mg/L	0.00	1.37
H3	9.11.2016 09:20:17	Fe (259.940 nm)	0.24	mg/L	0.00	0.44
H4	9.11.2016 09:21:43	Fe (259.940 nm)	0.19	mg/L	0.01	2.65
H5	9.11.2016 09:23:06	Fe (259.940 nm)	0.29	mg/L	0.00	1.41
M1	9.11.2016 09:24:15	Fe (259.940 nm)	0.36	mg/L	0.00	1.04
M2	9.11.2016 09:25:21	Fe (259.940 nm)	0.33	mg/L	0.01	1.65
M3	9.11.2016 09:26:30	Fe (259.940 nm)	0.33	mg/L	0.01	2.76
M4	9.11.2016 09:27:36	Fe (259.940 nm)	0.43	mg/L	0.01	1.38
M5	9.11.2016 09:44:18	Fe (259.940 nm)	0.321	mg/L	0.00	1.48

Calibration Curves:



Fe (259.940 nm)  
Intensity = 2491.84 \* Concentration - 8.14  
Correlation coefficient: 0.99992

Standards	Intensity	Method Concentration	Actual Concentration	% Error
Blank	-0.03	0.00	0.00	N/A
Standard 1	112.94	0.05	0.05	0.00
Standard 2	363.60	0.15	0.15	0.00
Standard 3	609.88	0.25	0.25	0.00
Standard 4	857.76	0.35	0.35	0.00
Standard 5	1115.63	0.45	0.45	0.00
Standard 6	1247.24	0.50	0.50	0.00

## Appendix C: Water quality of Mätäjoki (1982-2005) [70]

Liite 3. Veden laadun seurannan 1982 - 2005 tulokset

	Näytepiste	Näytteenotto- päivämäärä	Kokonaissyvyys m	Näkösyvyys m	Jäljen paksuus m	Lämpötila °C	pH	Alkaliteetti mmol/l	Väri/luku mg Pt/l	Sameus FTU	Käntöaine mg/l	Typen kokonaispit. µg/l	Fosforin kokonaispit. µg/l	Lämpökest kolimuotoiset bakteerit pmy/100 ml	Fekaaliset streptokokit pmy/100 ml	Escherichia coli - bakteerit mpn/100 ml	Hapen kylläisyaste %	Hapen pitoisuus mg/l	COD, Mn (O) mg/l	Rauta µg/l	Sähkön- johtavuus mS/m	
	P28	15.10.2003	0,2	0	5,8	7	1,18	35	6,3	5,8	3100	88	880				90	11,5	4	730	74	
	P28	8.7.2004	0,2	0	13	7,1	1,24	35	7,8	8	2700	17				3700	93	10	4	780	83,4	
	P28	15.11.2004	0,3	0	7,1	6,7	1,08	180	34	27	2800	82				280	82	9,9	7	3400	45,8	
	P28	28.7.2005	0,2	0	17	7,8	1,48	40	10	3	880	24				310	92	8,9	5	950	49,5	
	P281	9.4.2001	0,5	0	3	6,8			25	21	3000	120	58					28			43,2	
	P281	17.4.2001	0,3	0	2,5	6,7			24	20	2800	82	140					8			45,7	
	P281	23.4.2001	0,4	0	6	6,7			33	28	2400	87	88					7			41	
	P281	7.5.2001	0,2	0	0,5	7			11	12	2200	87	850					4			58,4	
Mätäjoki	P29	20.7.1987	0,2	0	15	7,2	1,78	80	11	8	2000	210	9700	690		57	5,9	8	1800	39		
	P29	19.10.1987	0,2	0	7,4	7,3	1,28	120	23	18	1800	130	650	100		83	10,1	19	2500	33		
	P29	27.7.1988	0,3	0	18	7,2	0,88	80	17	18	1400	120	2200	550		77	7,3				30	
	P29	24.10.1988	0,2	0	2,3	7,1	2,7	75	29	20	7000	98	6400	570		81	11,2	12	4200	83		
	P29	19.7.1989	0,4	0	15	7,5	1,43	125	15	11	1500	150	700	280		78	7,8	9	2200	95		
	P29	18.10.1989	0,3	0	4,7	7,4	1,08	80	21	18	1500	150	670	870		69	9	8			54	
	P29	10.7.1990	0,4	0	18	7,8	1,58	90	10	5,5	1700	89	8200	1400		68	6,7	10			38	
	P29	5.11.1990	0,2	0	4,5	7,3	0,73	200	45	29	2300	120	580	500		89	11,8	12			27	
	P29	23.7.1991			18	7,4	1,08	100	17	11	1400	120	510	280		79	7,8	10			27	
	P29	1.7.1992	0,3	0	15	7,2	1,71	200	67	57	1500	180	4300	1500		58	5,8	8			41,7	
	P29	9.9.1992	0,4	0	13	7,2	1,44	180	23	14	1900	140	2700	950		87	9,2	11			35	
	P29	9.8.1993	0,5	0,2	0	14	7,8	1,88	75	29	9,8	2900	75	4500	2500		85	8,8	8			46,9
	P29	20.9.1993	0,4	0,2	0	5,5	7,5	2,01	100	37	29	3200	85	1800	710		80	10,2	8			45,5
	P29	18.8.1994	0,2	0	18	7,4	1,81	100	7,3	9,8	1800	89	120	37		62	6,2	9	2000		39,4	
	P29	17.10.1994	0,3	0	3,5	7,4	1,48	250	18	14	1400	77	540	140		89	12	11	2200		39,1	
	P29	14.8.1995	0,2	0	14	7,5	1,82	120	8,8	5,8	1100	57	250	55		67	7,1	8	1400		47	
	P29	22.8.1996	0,3	0	18	7,5	1,73	100	18	10	1000	78	940			82	8,1	10	1800		49,9	
	P29	4.11.1996	0,3	0	8,2	7,1	0,53	100	27	23	1300	78	330			90	10,8	10	2100		20,5	
	P29	21.7.1997	0,3	0	17	7,4	1,08	80	9,2	7,8	750	98	400			94	9,1	8	1800		25,3	
	P29	30.7.1998	0,4	0	15	7,3	0,95	80	12	19	830	120	3400			81	8,2	11	1800		25,4	
	P29	13.10.1998	0,4	0	8,7	7	1,25	100	17	12	1200	130	540			85	10,1	11	2100		31,2	
	P29	28.8.1999	0,4	0	14	6,8	1,07	50	8,7	8	750	100	610			89	9,2	8	1300		26,5	
	P29	1.11.1999	0,3	0	7,1	7	1,48	25	13	10	1500	87	7800			87	10,5	7	1500		48,4	
	P29	28.7.2000	0,6	0	18	7,4	0,87	80	27	28	1000	140	2800			90	8,9	9	2900		23,4	
	P29	28.10.2000	0,5	0	9,2	7,2	0,82	150	43	35	1200	170	13000			89	10,3	10	3100		23,3	
	P29	30.7.2001	0,3	0	20	7,8	1,5	50	7,2	5	1100	180	570			91	8,4	8	1800		33,6	
	P29	29.10.2001	0,5	0	8,5	7,5	1,51	125	18	15	1300	130	690			91	10,8	18	2200		38,2	
	P29	8.7.2002	0,5	0	18	7,4	0,88	50	12	9	980	92	2300			87	8,4	8	1500		21,9	
	P29	6.11.2002	0,2	0	0,3	7,3	1,1	80	10	8	830	71	870			88	12,8	4	1300		45,6	
	P29	30.8.2003	0,3	0	15	7,4	1,14	70	7,8	13	910	83	1200			90	9,3	8	1500		31,3	
	P29	8.7.2004	0,4	0	14	7,2	1,02	140	21	14,4	1600	70			3100	95	10	13	2000		35,5	
	P29	15.11.2004	0,3	0	5,8	7,2	1,02	180	31	11	1700	85			1700	91	11,6	14	2200		28,9	
	P29	28.7.2005	0,4	0	18	7,5	1,08	50	6,4	4,5	680	88			370	87	8,4	7	980		22,5	

## Appendix D: Water quality of Haaganpuro (1982-2005) [70]

Mätäpuro	P30	20.7.1987	0,1	0	15	7,3		100	35	39	1600	100	2300	300	87	9			
	P30	19.10.1987	0,3	0	6,6	7,4	1,4	140	42	28	1400	100	780	160	86	10,7	9	3000	38
	P30	27.7.1988	0,3	0	18	7,2	1,5	30	27	6,4	1200	43	5300	1200	57	5,5			37,8
	P30	24.10.1988	0,2	0	2,5	7,3	1,92	75	51	44	3000	99	940	310	80	11	11	4400	52
	P30	19.7.1989	0,3	0	14	7,2	0,96	200	110	87	1700	280	2700	2400	66	6,9	15	5500	22
	P30	16.10.1989	0,3	0	5,1	7,5	1,36	125	41	22	1800	110	1600	870	66	8,4	9		37
	P30	10.7.1990	0,5	0	15	7,5	1,23	125	46	40	1400	120	2200	1900	65	6,5	9		30
	P30	23.10.1990	0,5	0	4,6	7,3	2,15	200	84	58	4100	140	4200	410					50
	P30	23.7.1991			15	8	1,74	125	54	56	1900	180	3300	570	66	6,5	11		38

Liite 3. Veden laadun seurannan 1982 - 2005 tulokset

Näytteenotto- päivämäärä	Kokonaisjärkyvyys m	Näköisyys m	Jään paksuus m	Lämpötila °C	pH	Alkaliteetti mmoli	Väri/kuu mg Pt/l	Sämsus FTU	Kimosaite mg/l	Typpien kokonaispät. µg/l	Fosforin kokonaispät. µg/l	Lämpökäest. kolimuutokset pmy/100 ml	bakteerit pmy/100 ml	Fekaliset streptokokit mpn/100 ml	Escherichia coli - bakteerit mpn/100 ml	Hapen kylläisyysaste %	Hapen pitoisuus mg/l	CO <sub>2</sub> Min (O) mg/l	Rauta µg/l	Sinkkin- jonhavuus mS/m
P30	1.7.1992	0,2	0	16	7,5	1,73	150	11	10	1200	69	630	380	1400	79	7,8	8		44,5	
P30	9.9.1992	0,3	0	14	7,3	1,63	150	38	28	2900	120	18000	1400	390	86	8,9	10		36	
P30	9.8.1993	0,2	0	15	7,6	1,34	75	13	16	1000	100	1500	390	17	85	8,6	12		32,6	
P30	20.9.1993	0,2	0	6,2	7,4	1,89	80	13	8,2	1000	63	53	17	85	10,6	8		46,3		
P30	16.8.1994	0,3	0	14	8,7	1,53	100	24	24	3100	90	640	500	81	8,3	7	2200	46		
P30	20.10.1994	0,2	0	2,5	7,2	3,11	250	43	35	2000	140	7000	640	49	6,7	11	3400	60,2		
P30	14.8.1995			14	8,3	1,66	60	12	8,4	1000	53	14000	1300	109	11,5	3	970	37		
P30	30.10.1995	0,4	0	6,5	7,4	1,62	75	30	23	1900	66	6500	640	75	9,3	7	2400	40,7		
P30	22.8.1996	0,4	0	15	7,7	2,17	80	19	17	1100	81	5700	640	88	8,9	7	1600	52,6		
P30	4.11.1996	0,5	0	8,5	7,2	0,8	100	78	61	1800	120	6900	640	82	9,7	14	4800	22,2		
P30	21.7.1997			16	7,7	1,91	60	29	27	950	84	4600	640	93	9,2	7	2100	49,1		
P30	27.10.1997	0,4	0	2	7,5	2,06	20	56	57	1500	150	8700	640	80	11	8	4300	54,1		
P30	30.7.1998	0,6	0	14	7,3	1,31	140	43	31	1400	140	4800	640	79	8,1	11	3500	32,4		
P30	13.10.1998	0,4	0	8,6	7	1,58	200	61	40	1500	150	9400	640	83	9,8	14	4400	36,7		
P30	26.8.1999	0,5	0	13	7,1	1,73	50	18	12	1100	79	3700	640	85	8,9	5	1600	43,2		
P30	1.11.1999	0,4	0	7,9	7,1	1,99	25	20	15	1700	79	12000	640	84	10,2	7	1600	53,7		
P30	26.7.2000	0,5	0	15	7,3	1,03	100	44	32	970	100	12000	640	84	8,5	8	3200	26		
P30	26.10.2000	1	0	9,7	7,1	0,56	160	110	85	1100	180	6300	640	81	9,3	7	5200	11		
P30	30.7.2001	0,5	0	18	7,7	2,5	40	16	8,8	1300	160	8200	640	86	8,3	6	1400	63,9		
P30	29.10.2001	0,5	0	8,9	7,4	1,54	75	23	12	1100	89	600	640	83	9,8	5	1800	38,1		
P30	8.7.2002	0,6	0	16	7,3	1,22	250	45	16	1700	120	9500	640	82	8,3	8	2700	31,1		
P30	6.11.2002	0,4	0	1,9	7,4	1,78	80	30	21	1100	85	5600	640	82	11,7	5	1800	54,4		
P30	30.6.2003	0,4	0	12	7,5	1,9	50	36	33	1400	120	1700	640	82	8,8	6	3000	55,3		
P30	29.10.2003	0,4	0	4,7	7,3	1,72	140	37	18	1400	110	2900	640	86	11,3	7	2400	63		
P30	8.7.2004	0,5	0	12	7,5	1,79	160	58	37,3	2000	84		640	5200	89	9,6	12	3000	52,2	
P30	15.11.2004	0,5	0	7	7,3	1,35	250	39	15	1900	90		640	6500	89	10,8	15	2700	39,5	
P30	26.7.2005	0,5	0	15	7,6	1,67	60	16	9	1000	48		640	3300	87	8,8	4	1100	46,5	



## Appendix E: Water quality of Mätäjoki and Haaganpuro in 2004 [69]

Vuoden 2004 vesinäytteiden tulokset

Näytepiste	Puro	Näytteenottopäivä				Lämpötila °C				pH				Hapen pitoisuus mg/l				Hapen kyllästysaste %				Sähkönjohtavuus mS/m						
		talvi (II)	kevät (IV)	kesä (VI)	syky (X)	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X			
1	Mätäjoki	10.2.04	26.4.04	29.8.04	25.10.04	-0,1	5,45	13,02	7,33	6,88	7,41	7,76	7,35	10,35	5,83	9,68	82,1	58,5	60,3	68,3	29	21	20					
		11.2.04	26.4.04	29.8.04	25.10.04	-0,2		13,83	7,39	6,9		7,74	7,33	13,26		9,6	89		57,4	79,7	68,6		21,4	19,9				
		11.2.04	26.4.04	29.8.04	25.10.04	-0,2	5,35	13,8	7,07	6,6	7,35	7,54	7,12	7,87	9,32	4,44	7,31	53	73,7	43	60,3	63,9	29,1	22	19,8			
		11.2.04	26.4.04	29.8.04	25.10.04	0	3,92	11,46	8,34	6,88	7,38	7,58	7,14	11,4	10,35	4,9	8	78	78,9	45	68,8	62,2	41,8	28,3	30,7			
			26.4.04	29.8.04	25.10.04		3,89	13,31	8,74		7,28	7,4	7,08		9,9	5,14	8,54		75,5	48,2	70		34	48,7	24,5			
			26.4.04	29.8.04	25.10.04		4,84	12,46	6,48		7,31	7,51	7,12		10,13	5,83	9,42		78,7	54,7	78,7		25,5	34,2	18,6			
			26.4.04	29.8.04	25.10.04		5,73	13,48	6,5		7,39	7,52	7,16		7,94	2,41	3,87		63,4	23,1	32,3		20,5	13,9	13,9			
8	Korppaanjo	10.2.04	26.4.04	29.8.04	25.10.04	0,2	8,77	16,25	7,84	7,03	7,16	7,85	7,2	5,8	7,81	2,78	4,15	48	67,4	28,3	35	63,2	53,5	22,9	27,1			
9	Mätäjoki	10.2.04	26.4.04	29.8.04	25.10.04	-0,1		12,49	7,25	7,25		7,87	7,3	14		5,44	9,47	88		51,1	78,8	64,7		38,2	26,5			
		11.2.04	26.4.04	29.8.04	25.10.04	-0,1	1,4	12,79	6,09	6,96	7,33	7,68	7,37	13,1	10,55	5,93	9,17	88	75,1	56,1	73,9	45	19,5	21,4	18,9			
		11.2.03	26.4.04	29.8.04	25.10.04	-0,1	7,78	12,89	7,58		7,57	7,78	7,17		10,33	5,72	9,02		68,9	54,2	75,5		37,8	35,2	29,3			
		11.2.04	26.4.04	29.8.04	25.10.04		4,98	12,63	7,25		6,81	7,43	7,73	7,27		10,14	5,89	9,65		79,4	55,5	80,1		58,1	29,7	33,9	21,4	

Vuoden 2004 vesinäytteiden tulokset

Näytepiste	Puro	Kiintoaine mg/l				Organinen kiintoaine mg/l				Väri luku mg/l Pt				Sameus FTU				Alkaliteetti mmol/l				Sulfaatti mg/l					
		II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X		
1	Mätäjoki	6,98	6,37	8,88	12,78	1,88	1,33	2,18	2,22	15	40	45	100	12	11	12	27	0,627	1,008	0	0,897	57,8	58,8	22,0	34,8		
		7,78	5,10	8,02	11,50	2,10	1,15	1,82	2,76	15	40	50	100	13	10	13	28	1,048	0,987	0,890		60,0	47,2	22,0	34,3		
		6,48	5,88	7,78	13,08	1,16	1,10	2,16	2,80	15	40	50	125	13	12	14	27	1,089	0	0,938	0,943	57,5	55,8	23,5	33,8		
		3,14	6,73	20,98	11,33	1,14	1,90	3,82	2,52	25	40	60	125	5,2	14	19	22	1,409	1,003	1,243	1,598	61,6	47,7	32,8	41,5		
			5,17	12,68	26,78		0,85	2,74	4,28		50	90	100		13	28	36		0,858	1,251	1,038		55,3	51,6	35,1		
			4,07	4,72	7,98		0,37	1,32	1,16		60	90	150		7,9	12	20		0,701	0	0,907		38,1	27,8	21,5		
			2,39	2,63	12,54		0,44	1,23	2,54		50	40	125		6,2	4,8	30		1,054	0,825	0,885		30,1	10,8	14,4		
8	Korppaanjo	7,40	8,16	3,43	19,18	2,88	2,28	1,63	5,04	20	25	40	80	9,1	10	7,1	20	2,409	1,638	1,201	1,834	60,7	66,0	14,8	33,7		
9	Mätäjoki	15,10	8,21	17,78	11,50	1,60	0,98	2,60	1,93	25	50	50	150	11	18	24	31	1,833	1,383	1,825	0	48,5	41,8	28,9	26,7		
		1,50	11,23	4,89	9,20	0,27	1,52	0,63	1,83	45	80	80	150	9,3	19	13	22	0	0,388	1,108	1,101		57,3	45,2	22,2	23,3	
		4,59	11,81	6,99	17,78	0,78	1,13	1,10	2,60	10	40	40	75	4,3	18	12	38	1,845	0	1,627	1,710	42,3	44,2	28,2	31,8		
12		7,80	15,12	8,07	42,77	0,82	1,85	1,15	4,37	30	60	75	200	11	28	23	80	0,939	0,712	1,209	1,058	44,2	35,5	25,5	27,1		

## Appendix F: Nutrients concentration in Mätäjoki and Haaganpuro in 2004 [69]

Vuoden 2004 vesinäytteiden tulokset

Näytepiste	Puro	Typen kokonaispit.				Ammoniumtyppi				Nitraattityppi				Escherichia coli -bakteerit				Enterokokit				BOD7				COD,Mn(O)			
		II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X
1	Mätäjoki	1,8	1,8	1	1,8	0,38	0,10	0,18	0,08	1,14	1,21	0,38	0,91	920	370	730	1600	140	210	210	360	2	2	3	1	5	9	9	15
2		1,9	1,7	0,98	1,7	0,43	0,10	0,18	0,08	1,07	0,78	0,35	0,88	1000	180	530	440	110	32	170	330	1	2	2	3	4	8	8	15
3		1,8	1,6	0,94	1,8	0,38	0,10	0,18	0,08	1,08	1,10	0,33	0,87	850	210	650	410	65	17	170	340	1	2	2	4	5	9	8	16
4		2,4	1,9	1,3	2,2	0,42	0,11	0,23	0,07	1,58	1,42	0,73	1,24	2400	1400	2000	490	>2000	29	330	120	2	2	3	3	5	8	8	19
5			1,3	1,2	1,8		0,10	0,27	0,09		0,71	0,44	0,82		18	340	210		6	77	45		1	2	3		8	10	18
6			3,3	1,7	2,7		0,49	0,08	0,23		2,45	1,12	1,45		4800	920	41		280	200	38		2	2	3		10	13	25
7			1,1	0,57	1,4		0,01	0,08	0,05		0,61	0,15	0,49		1700	98	1300		33	57	230		2	2	6		10	8	17
8	Korppaanaja	3,9	2,5	1,2	1,8	1,40	0,20	0,54	0,28	1,62	1,48	0,20	0,59	4600	170	130	180	280	13	23	330	48	5	6	4	8	9	8	12
9	Mätäpuro	1,8	1,7	1,5	1,9	0,22	0,14	0,33	0,18	1,13	1,15	0,81	0,90	17000	870	>2400	4100	250	220	300	2800	2	2	4	2	5	8	8	18
10		2,2	1,6	1,1	1,7	0,10	0,08	0,08	0,07	1,72	1,23	0,49	0,87	1	71	410	32	1	8	390	28	1	2	2	3	6	9	10	20
11		0,83	1,4	0,99	1,9	0,04	0,02	0,18	0,05	0,64	1,08	0,57	1,21	6	19	580	37	8	24	77	41	1	1	<2	2	2	5	5	12
12		1,2	1,8	1,3	2,2	0,03	0,07	0,12	0,05	0,80	1,25	0,72	1,28	3	75	370	37	2	28	170	67	6	2	2	2	6	10	9	21

Vuoden 2004 vesinäytteiden tulokset

Näytepiste	Puro	Natrium				Kalium				Magnesium				Kalsium				Fluori				Kloridi				Fosforin kokonaispit.			
		II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X	II	IV	VI	X
1	Mätäjoki	84,5	38,9	22,7	18,8	6,1	5,1	3,3	4,5	9,0	8,1	4,1	5,3	38,8	38,8	21,1	23,7	0,5	0,3	0,2	0,2	112	41,2	33,9	24,9	21	36	73	73
2		80,8	38,8	23,2	18,7	6,2	5,2	3,3	4,2	9,4	8,1	4,3	5,3	39,8	37,8	22,0	23,3	0,5	0,3	0,2	0,2	6,8	38,5	34,8	24,5	27	28	72	80
3		77,2	39,8	23,7	18,8	6,3	5,1	3,5	4,7	9,0	8,1	4,4	5,4	39,5	35,9	22,7	23,8	0,5	0,3	0,2	0,2	14,8	40,9	35,3	24,8	25	21	59	79
4		70,2	84,8	37,8	37,1	6,4	5,1	4,8	5,7	8,7	7,0	4,9	6,1	45,8	38,1	30,2	35,5	0,5	0,3	0,3	0,3	31,1	112	41,2	42,8	30	14	80	58
5			50,5	60,8	28,0		7,0	6,0	5,2		8,0	7,7	5,2		40,3	48,4	26,8		0,3	0,4	0,3		24,8	3,4	36,9		15	79	86
6			33,3	48,7	23,1		2,8	4,1	3,3		5,4	6,4	4,4		24,7	30,8	20,8		0,3	0,3	0,2		40,2	37,5	28,2		36	64	61
7			25,4	13,5	12,4		3,4	2,0	3,9		6,2	3,3	4,2		27,3	15,8	18,4		0,3	0,2	0,2		38,4	21,3	18,8		41	69	95
8	Korppaanaja	94,3	83,7	24,7	27,1	11,1	9,3	4,3	6,3	13,3	12,2	4,3	6,8	57,0	47,1	23,7	34,9	0,5	0,3	0,2	0,2	125	111	31,7	38,1	121	50	283	138
9	Mätäpuro	75,5	47,9	52,7	28,0	5,4	4,0	4,7	4,1	10,3	7,5	7,1	6,2	48,1	41,3	38,4	31,7	0,5	0,3	0,3	0,3	19,9	26,5	36,4	35,5	21	31	81	82
10		48,0	28,5	25,1	18,2	4,4	3,5	3,8	3,9	7,0	3,8	3,9	3,7	32,8	18,9	24,2	23,0	0,5	0,3	0,2	0,2	50,0	41,5	31,3	17,0	21	45	48	85
11		82,2	58,2	47,7	34,0	5,2	4,5	4,0	4,1	11,1	9,4	6,9	7,2	48,8	38,8	34,8	35,5	0,8	0,3	0,3	0,3	7,4	22,9	40,2	43,0	11	14	41	83
12		73,5	50,0	48,9	22,4	4,1	3,4	4,2	4,0	7,8	6,0	5,6	5,3	38,2	31,7	34,8	28,3	0,5	0,2	0,2	0,2	18,0	28,1	39,4	31,1	16	45	79	118



### Appendix G: Sampling sites of Mätäjoki





## Appendix H: Sampling sites of Haaganpuro





## Appendix I: Instruments used during onsite measurements

