TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

TOTAL MAXIMUM DAILY LOAD OF NUTRIENTS FOR 14 ESTONIAN RIVERS DISCHARGING TO THE BALTIC SEA

LÄÄNEMERRE SUUBUVA 14 EESTI JÕE LUBATAV PÄEVANE TOITAINETE KOORMUS

MASTER THESIS

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Tallinn 2021

(*On the reverse side of title page*)

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Environmental Engineering and Management

THESIS TASK

Student: Diego Alejandro Velasquez Ordoñez, 195429EABM

Study programme: EABM, Environmental Engineering and Management

main speciality:

Supervisor(s): Dr. Prof. Arvo Iital

Thesis topic:

(in English) TOTAL MAXIMUM DAILY LOAD OF NUTRIENTS FOR 14 ESTONIAN RIVERS DISCHARGING TO THE BALTIC SEA

(in Estonian) LÄÄNEMERRE SUUBUVA 14 EESTI JÕE LUBATAV PÄEVANE TOITAINETE KOORMUS

Thesis main objectives:

1. Describe the nutrients situation in the Baltic Sea, Gulf of Finland and Estonia
2. Gather nutrient and flow data from the monitoring stations of the studied river
3. Analyse the results of each river

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Literature review, including methodology and policy goals for redction of nutrient load to the Baltic Sea	January 2021
2.	Data collection. Daily flow and water chemistry data for 14 rivers discharging to the Baltic Sea	March 2021
3.	Calculation of the daily allowable maximum loads for the rivers based on the quality targets	April 2021

Language: English **Deadline for submission of thesis:** “.......”.........20….a

Student: Diego Alejandro Velasquez Ordoñez ....

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Head of study programme: Dr. Prof. Karin Pachel ....

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1 PREFACE

The past months have been an exciting journey as I have been writing what will be the finishing step before culminating my master's in environmental engineering and management at Tallinn University of Technology: my master's thesis. During this period, I was helped and supported by many people to which I would like to express my sincere gratitude to all of them for their sincere support.

First, I would like to express my gratitude to my thesis supervisor, Dr. Aarvo Iital, who provided me with ideas on what to research, and the necessary support and guidance on how to structure my work. His valuable comments as my professor and feedbacks as my thesis supervisor will always be appreciated.

My gratitude also goes to all my friends, fellow classmates, and professors with whom I crossed paths during these past 2 years of my master's degree as all the knowledge that I have learned from them has guided me to this moment.

Finally, I wish to thank all the people dearest to me: My parents, Ricardo and Yolanda, as they have always been my role models and as civil engineers have provided me with their knowledge, wisdom, and guidance throughout my studies. My brothers, Ricardo and Pablo, and my niece, Elizabeth, that even when being at distance they always have my back. Their love and support have been of great importance to me.

List of abbreviations and symbols

EU	European Union
WFD	Water Frame Directive
BS	Baltic Sea
N	Nitrogen
P	Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
MAI	Maximum Allowable Inputs
GUF	Gulf of Finland
TMDL	Total Maximum Daily Load
WLA	Wasteload Allocation
LA	Load Allocation
MOS	Margin of Safety
FDC	Flow Duration Curve
LDC	Load Duration Curve
HELCOM	Helsinki Commission
BSAP	Baltic Sea Action Plan
MWWTP	Municipal Wastewater Treatment Plant

2 INTRODUCTION

It is a reality that all the elements that comprise the management of water resources must be reviewed in the light of new paradigms and approaches as some of the major causes of environmental threats are caused by water-based contaminates. It is important to follow a planned and strategic action, mainly because water as a resource represents a fundamental element not only for development but also the very sustenance of life. The European Union (EU), under its Water Frame Directive (WFD) (2000/60/EC) has as an objective to protect and enhance the status of its surface waters (rivers, lakes, transitional and coastal waters) as well as its groundwater [1].

The Baltic Sea (BS) is subjected to several environmental threats due to Climate Change, to which the most widely threats are the rise of average temperature and increase in rainfall; and these threats will consequently raise the BS catchment area and cause a significant amount of key nutrient inputs: Nitrogen (N) and Phosphorus (P) [2]. The annual water flow to the BS in 2017 has already shown an important increment of 5 % higher than the average water flow from the years 1995 – 2017. Along with the increment in the annual water flow, there has been changes in the annual waterborne inputs of Total Nitrogen (TN) and Total Phosphorus (TP) with an increment of 12 % for TN and a decrement of 14 % for TP from their average inputs from the years 1995 – 2017 [3]. Based on the Maximum Allowable Inputs (MAI) for N and P from the seven sub-basins of the BS, reductions were seen needed for N in three sub-basins and in three sub-basins for P [4], and in order to achieve the allowable levels, further reductions are still needed for in some sub-basins [5], and the GUF appears in both lists.

The GUF is considered to have eutrophic waters because of its input of nutrients through natural and anthropogenic sources, causing the GUF to have a nutrient load per unit of surface area higher than most to the other sub-basins of the BS [6]. In terms of water flow, the GUF has exceeded its long time average, and with that, since 2007 (to 2013) it has surpassed its average level of riverine TN inputs and it has lower in TP [7]. In order to provide a comprehensively basin-wide study of the riverine nutrient load inputs into the GUF, the monitoring of the daily flow measurements is needed along with its daily load inputs.

The goal of this thesis is to provide a Total Maximum Daily Load (TMDL) study for 14 rivers from Estonia which discharge to the BS. By analyzing each river using the TMDL methodology, an evaluation is going to be developed of the existing water quality for a specific pollutant, N and P, in each river. For the purpose of this study, the selected pollutants are N and P, as their input from the rivers into the GUF (and consequently, the BS itself) causes the increase of organic matter in the zone, and therefore increase the severity of eutrophication in the area.

2.1 Total Maximum Daily Flow (TMDL)

The TMDL is a quantitative regulatory system of the pollutants discharged from each of the Estonian rivers into the GUF. This management system is a policy for the new era to achieve both economic development and water conservation by being able to maintain the established standard once they are met [8]. In this thesis, the TMDL has the purpose to establish the maximum levels of pollutants (N and P) that each of the 14 rivers can take without exceeding the standards established for water quality. Standards are then used to determine the waters that are impaired and what can be done for its improvement.

A TMDL can be considered a tool (or a target) to achieve the water quality control goals from both point sources and non-point sources, and this tool is indispensable for the study area considering that the established targets for both N and P have not been met in the GUF (even considering the reduction of P in recent years).

In general, a TMDL can be considered to be both: a planning process that attains water quality standards and a quantitative assessment of the pollution sources at stake and the pollutant reduction needed to restore and protect those impaired waters (which can be rivers, lakes, or streams) [9].

The TMDL is calculated based on the Waste load allocation (WLA) consisting of point sources, Load Allocations (LA) consisting of non-point sources of loads, and Margin of Safety (MOS) which addresses uncertainties in the analysis [10]. Having this information, the appropriate formula representation based on the real and simulated loads for TMDL is:

$$TMDL = \sum WLA + \sum LA + MOS$$

The aim goal of the TMDL is not to establish or modify regulatory controls on the pollution sources, nor to establish limits or standards in the discharge flows [9]. The aim is to estimate the allowable pollutant loads and allocate these discharge loads to know the pollutant sources (point or non-point sources) and establish the appropriate measure controls [11].

Flow Duration Curve

The Flow Duration Curve (FDC) for the different impaired waters is developed using the flow data available from the records of the different water quality monitoring stations. The historical data of the daily discharge flow in each river is used to relate the flow to the percent of time the values on the recorded data has been met or exceeded in a specific site.

When developing the FDC the daily discharge flow values must be ranked from the highest value to the lowest value from the recorded historical data, and using this convention, the percent of exceedance from each observed discharge flow can be calculated. An example of this is that the lowest value of the observed data has a flow exceedance frequency of 99.9 %, meaning that the value of the lowest observed data is met or exceeded 99.9 % of the time. Therefore, zero corresponds to the highest stream discharged value from the observed data and 100 % corresponds to the lowest value. In an FDC chart, the x-axis runs from highest value to lowest value, from left to right respectively.

Load Duration Curve

The Load Duration Curve (LDC) uses the FDC as the foundation for its development. Therefore, to develop the LDC it is necessary to first construct the FDC of the hydrological streamflow data (Figure 2.1). The flow data is then multiplied by the desired target of the water quality and the conversion factor to achieve the result of the estimated pollutant load in tonnes per day (Figure 2.2).

When developing the LDC, the result can be used to show the maximum load a river can carry without exceeding the established targets criterion. It also shows at what section of the hydrological period it will exceed the target [12].

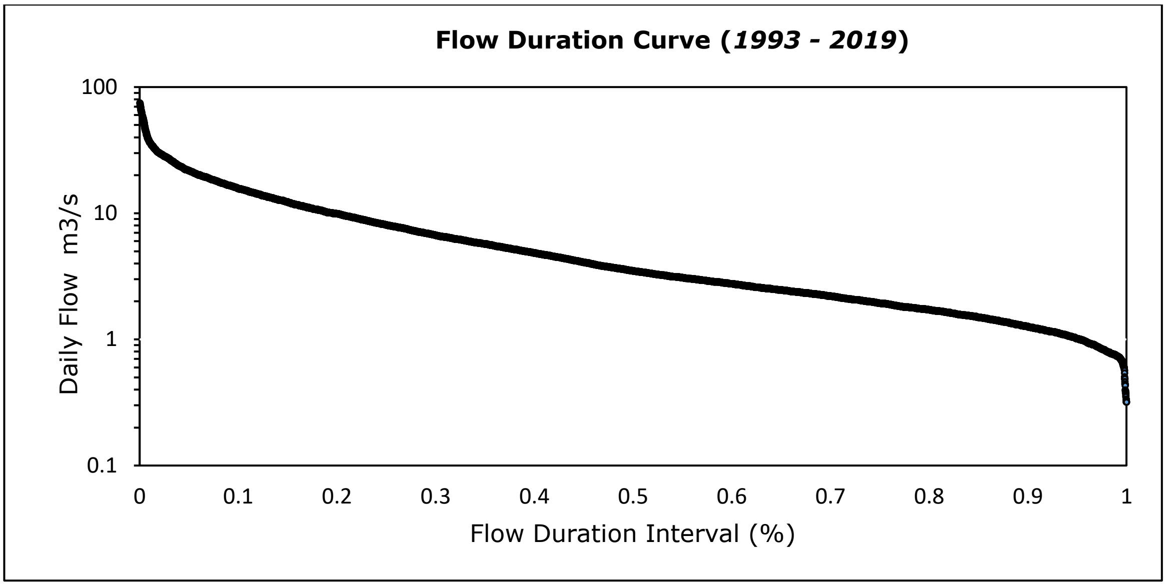


Figure 2.1: Sample Flow Duration Curve, Purtse river

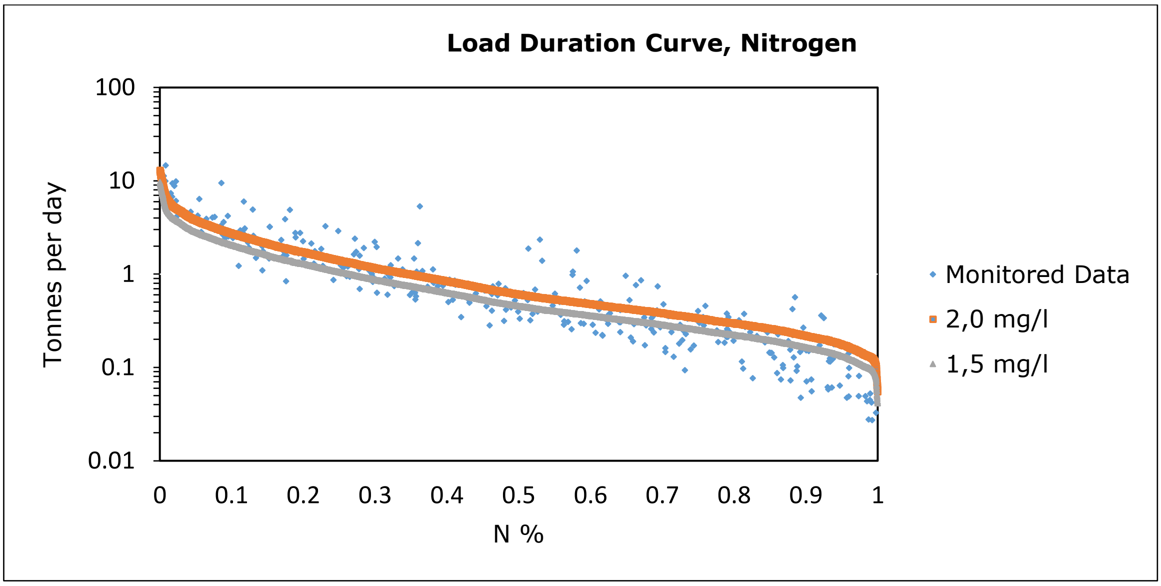


Figure 2.2: Sample Load Duration Curve for Nitrogen, Purtse river

Duration Curves Zones

The different zones in the Duration Curve serve as indicators of the hydrological conditions. These zones provide information to understand better the potential point or non-point sources of pollution.

There are 5 divisions (or zones) representing the daily flows in the river, illustrated in Figure 2.3. These divisions are: High flows: 0 – 10 %, moist conditions: 10 % - 40 %, mid-range flows: 40 % - 60 %, dry conditions: 60 % - 90 %, and low flows: 90 % - 100 % [11].

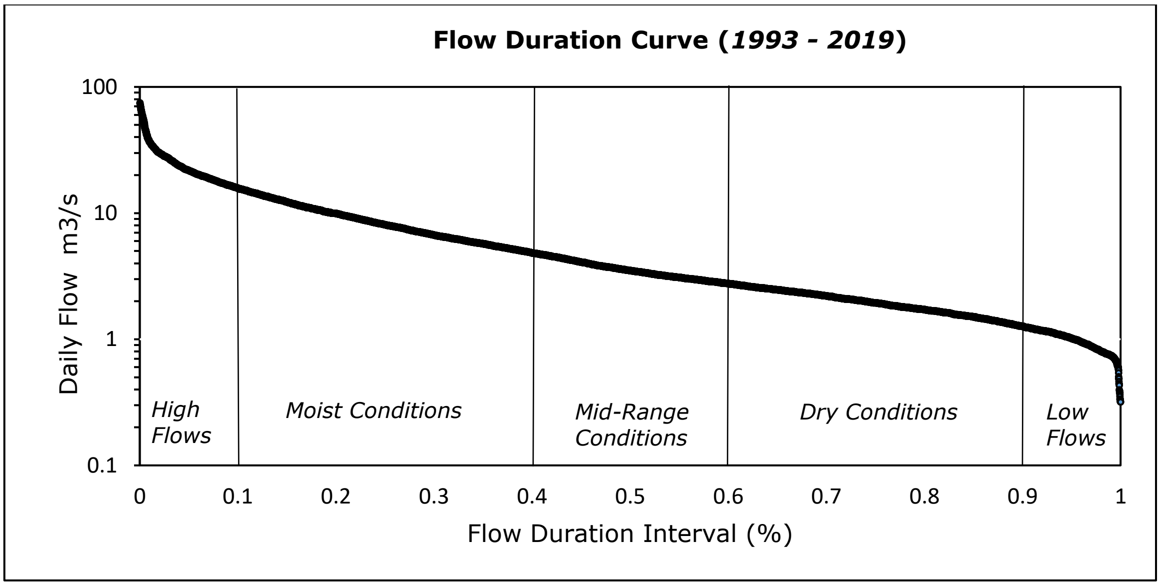


Figure 2.3: FDC divided by its five hydrological zones, Purtse river

Box and whiskers plot

In order to illustrate the monthly data distribution from the historical daily stream flow data gathered, the box and whiskers plot is used in this thesis. The purpose is to illustrate the variation of gathered data for the different months of the year.

It displays the distribution data in different percentiles: The bottom (lower quartile) and top (upper quartile) of the box represent the 25 th (0,25) and 75th (0,75) percentiles, respectively. The median represents the 50 th percentiles (0,5), or the middle of the data. The whiskers, or the vertical lines, represent the 10 th (0,1) and 90 th (0,9) (lower and upper extreme) percentile of the data set, and these whiskers at the plot are also used to detecting the outliers. The outliers are the data lying beyond the 10 th and 90 th percentiles, they are represented as a dot in the plot.

These quartiles are special percentiles and can be understood given the following explanation: The lower quartile represents 25 %, meaning that 75 % of data will be more than 25 % percentile. It is the same logic with the other percentiles.

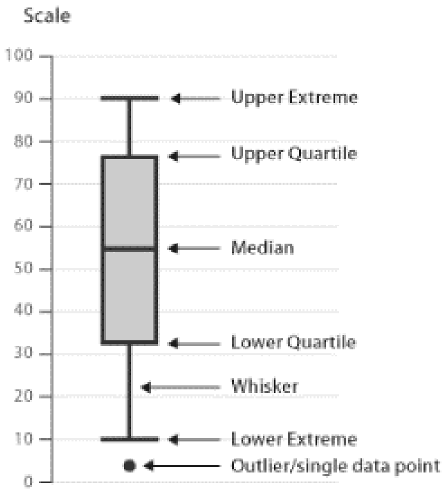


Figure 2.4: Box and Whiskers plot with its parameters [13]

2.2 Nutrient enrichment and eutrophication

Eutrophication is the process of pollution that occurs at a water body when there is an excessive amount of nutrients, N and P, and sometimes organic matter can result in undesirable effects [14]. Because of this excessive amount of nutrients, there is a growth in algae and other aquatic plants. Once these plants die, they decompose and, in that process, they take away oxygen in the water, and consequently making that body of water unable to sustain life [15].

It is important to recognize that the undesirable effects of eutrophication in our aquatic ecosystems is largely dependent on the anthropogenic activities, but the variation in meteorological and hydrographical conditions also have a significant role in the impacts of the nutrients entering the water bodies. From the impacts related to natural sources, precipitation leads to an increase in runoff which consequently leads to nutrient loss and nutrient inputs from the diffuse sources to the surface waters. In parts of the world where long winters are present covering the ground with snow and frosting the soil, nutrient leaching decreases and the riverine load inputs increases during the spring thaw.

Although natural conditions play an important role in nutrient inputs, human activities also share an important role. Globally, 80 % of municipal wastewater is discharged into the water bodies without the correct treatment and in some cases, even untreated [16], and in the EU, 38 % of the water bodies are subjected to significant pressure from the agricultural pollution [17].

In 2014, the BS catchment area agricultural land covered an area of 358,000 km² (21 %), Denmark with the highest percentage of area being cultivated with 61 % (followed by Poland 60 % and Germany 46 %) and Finland along with Sweden had the lowest proportion with 7 % each of its land being under cultivation [18].

Eutrophication is among the most influential environmental threat in the BS (and same for the GUF), the results for the study made in the years 2011 – 2016 showed that the BS suffered from eutrophication, but it also showed that the status has deteriorated in comparison to the status from the previous assessed years (2007 – 2011) [19].

Municipal wastewaters in the BS have seen an improvement in P removal during the last decade. By contrast, N removal is a recent development. Regulations have been important for the improvement in nutrient loads discharging by the municipal wastewaters. In Saint Petersburg, before 1978, the wastewaters were discharged directly (untreated) into the GUF of the River Neva. Nowadays, the N load has decreased by 60 % and the P load has decreased by 90 % [20].

Reducing the nutrient loads from agricultural sector is more difficult than reducing them from point sources. Even after implementations of the agricultural environmental measures, there could be a time gap between the implementation and the time the nutrients are leached (as it may continue to be high for some decades), nevertheless, the visible effects of the implemented measures will be seen eventually in the waterbodies.

For these reason, appropriate measures must be established for its mitigation (N and P) and to achieve the environmental quality standards.

3 STUDY AREA

3.1 The Baltic Sea

The BS covers 415, 226 km² in surface area, while its catchment area is around 1,7 million km² which extends over an area of four times itself [21], and it has an average depth of 50 meters. From the catchment area, 93 % belongs to the HELCOM contracting parties (Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Russia, Finland, and Sweden) and the rest 7 % lies in territories that are not part of the contracting parties (Norway, Ukraine, Belarus, Slovakia, and Czech Republic) [18]. The sub-catchment area division of the seven sub-basins (Archipelago Sea, Baltic Proper, Bothnian Bay, Gulf of Finland, Gulf of Riga, Kattegat, The Sound, and Western Baltic) in the BS can be seen in Figure 3.1.

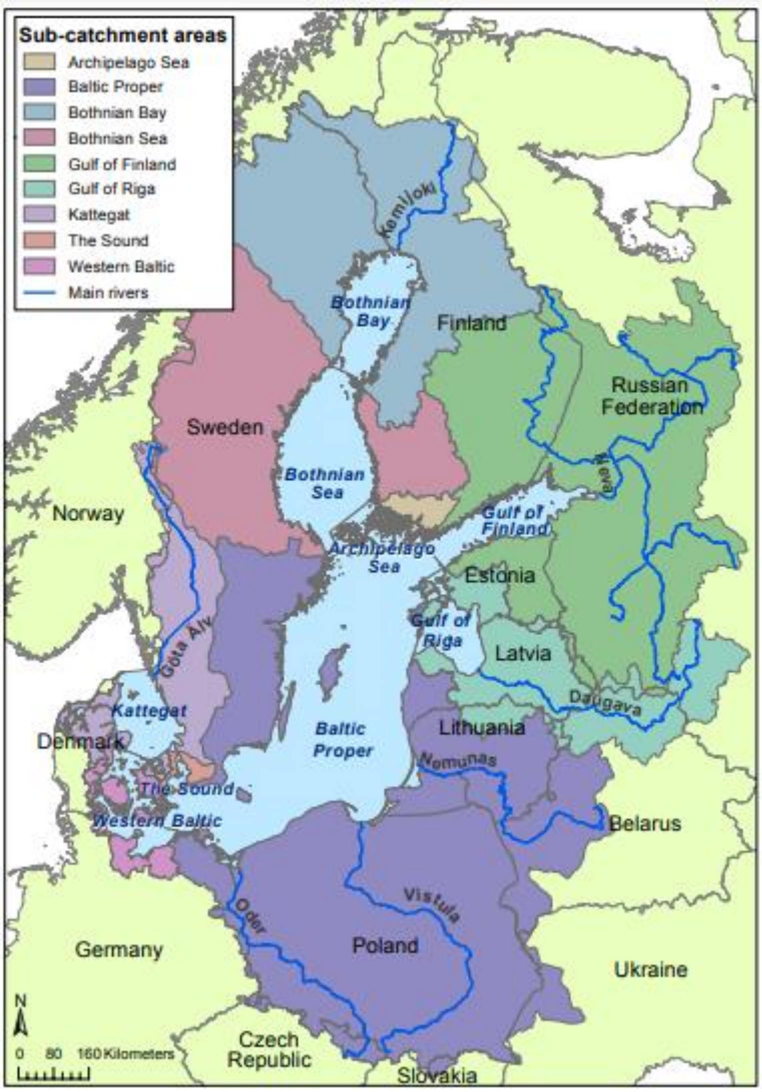


Figure 3.1: BS catchment area with its sub-basins and largest rivers [22]

Over 84 million people live in the catchment area of the BS, of which 64 % are living in the catchment of the Baltic Proper sub-basin and 45 % of the total population of 84 million live in the Polish territory [18]. Highest human population are found in the southern parts of the BS.

The seven largest rivers that discharge into the BS (Göta River, Kemi River, Daugava River, Nemunas River, Oder River, Vistula River, Neva River) take up to 51 % of the total catchment area. The importance of these rivers lies not only on their dimensions, but also the fact that nearly 55 million people live in the catchment of these seven rivers. This human pressure in the catchment can be seen mostly in the southern parts where the population is densest, and the agricultural practice is more intense [23]. Farmlands compose about 60 % to 70 % of the total catchment area in Germany, Denmark, and Poland. In Finland, Russia, Sweden, and Estonia, the catchment area is made up about 65 % to 90 % of forest, wetlands, and lakes [22].

Table 3.1: Physical characteristics of the BS sub-basins [21]

Sub-region	Area (km2)	Volume (km3)	Max. Depth (m)	Average depth (m)
Baltic Proper	211069	13045	459	62.1
Gulf of Bothnia	115516	6389	230	60.2
Gulf of Finland	29600	1100	123	38
Gulf of Riga	16330	424	>60	26
Danish Straits and Kattegatt	42408	802	109	18.9
Total Baltic Sea	415266	21721	459	52.3

Ecological objectives in relations with eutrophication has been adopted. The Helsinki Commission (HELCOM) has established the Baltic Sea Action Plan (BSAP) in 2007, which aims to monitor and assess the actions in the BS as eutrophication has been mentioned to be one of the four main issues to address in order to achieve the goal of improving the environmental health in its waters [14]. The BSAP eutrophication is addressed with the goal of achieving a “Baltic Sea unaffected by eutrophication” and “Environmentally friendly maritime activities”.

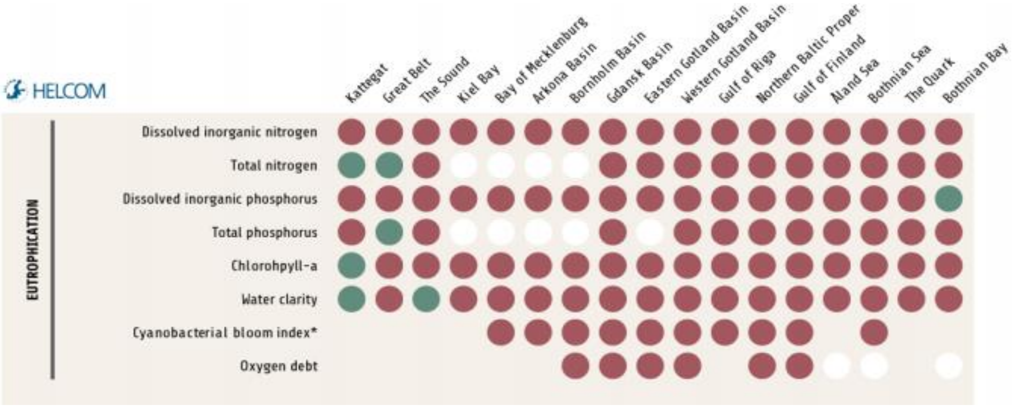


Figure 3.2: Status of eutrophication core indicators by sub-basin. Green circles indicate good status, red circles indicate not good status, and white circles indicates it has not been assessed [24]

The eutrophication status has been assessed and classified in 189 areas, from which 17 are open and 172 are coastal areas [25]. For the years 2011 – 2015, from an integrated eutrophication status, none of the 17 offshore sub-basins achieved good status and only 17 (3 %) of the 247 coastal assessment units achieved good status [26].

The BSAP and the Ministerial Declaration are aimed to reduce the nutrients inputs in the BS from different sources. For a better management and coordination, joint actions as well as national actions have been implemented. In figure 3.3, the specific topics expected to reduce its input of sources are listed.

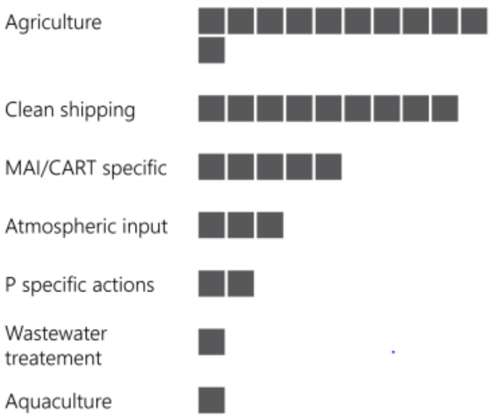


Figure 3.3: Actions to mitigate eutrophication. Each box represents one action [26]

Agriculture is the main source of nutrient inputs in the BS [27]. According to the HELCOM BSAP [24], about 75 % of the N load (other 25 % is via atmospheric deposition) and at least 95 % of P load entering the BS comes from rivers or as a direct waterborne discharge. In terms of indirect and direct loads for Municipal Wastewater treatment Plants (MWWTP), three countries contributed more than 20 % of NT loads: Poland 28

%, Russia 23 %, and Sweden 23 %. For TP, half of the loads originated in Poland [28], which has the biggest population.

Phosphorus has been the long-term focus to reduce nutrient loads, as it has been the main regulating nutrient for eutrophication (except for the saline waters) and less attention has been given to N, until more recently. For the BS in terms of riverine load, (Figure 3.4) the natural background represented 33 % of the TN and 33 % for the TP (without rounding 33.4 % for N and 32.9 for P [29]), almost one third of the nutrient input.

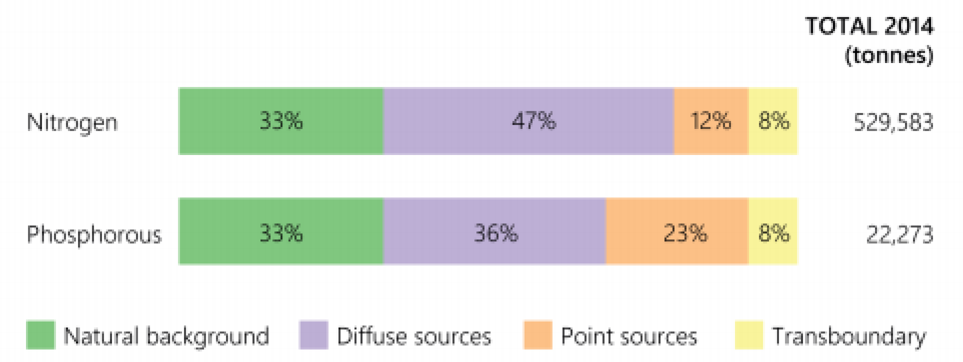
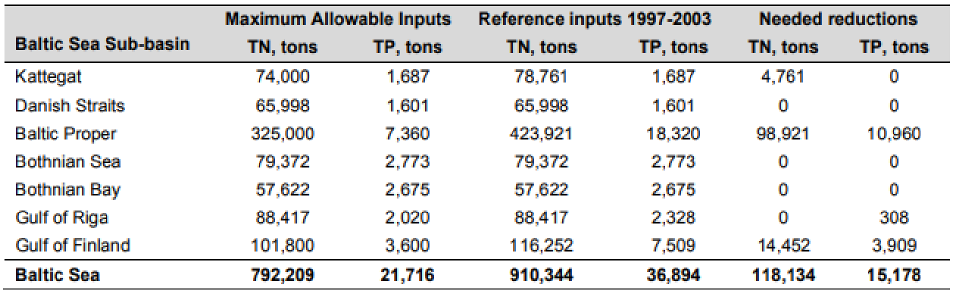


Figure 3.4: Sources of riverine loads in the BS in 2014 [26]

In order to protect the BS, environmental target indicator values have been agreed with the goal of achieving a good ecological and environmental status and if there is failure to achieve these targets, eutrophication will continue to affect the water quality and aquatic ecosystem. These indicators are the MAI, which targets were first introduced in the BSAP in 2007 and then updated in the Copenhagen Ministerial Declaration in 2013 and input of nutrients is one of the core pressure in the BS and therefore, these indicators must be reviewed and updated periodically.

The nutrient reduction scheme based on a revised data (2013) from a more complete dataset and eutrophication status targets, resulted in the following MAI.



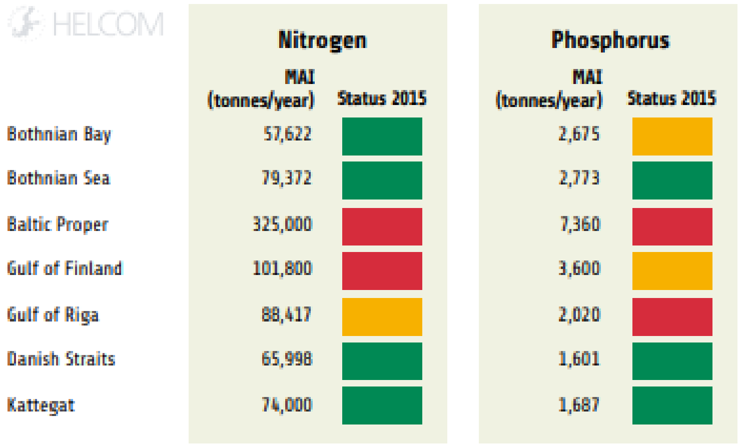
	Maximum Allowable Inputs		Reference inputs 1997-2003		Needed reductions	
Baltic Sea Sub-basin	**TN, tons**	**TP, tons**	**TN, tons**	**TP, tons**	**TN, tons**	**TP, tons**
Kattegat	74,000	1,687	78,761	1,687	4,761	0
Danish Straits	65,998	1,601	65,998	1,601	0	0
Baltic Proper	325,000	7,360	423,921	18,320	98,921	10,960
Bothnian Sea	79,372	2,773	79,372	2,773	0	0
Bothnian Bay	57,622	2,675	57,622	2,675	0	0
Gulf of Riga	88,417	2,020	88,417	2,328	0	308
Gulf of Finland	101,800	3,600	116,252	7,509	14,452	3,909
Baltic Sea	**792,209**	**21,716**	**910,344**	**36,894**	**118,134**	**15,178**

Figure 3.5: Sub-basins with their MAI, reference inputs, and needed reductions [4]

3.1.1 Maximum Allowable Inputs (MAI)

The HELCOM BSAP has set targets that represent the HELCOM long-term vision of the BS and the eutrophication status it aspires to achieve. In order to achieve a good environmental status in all seven sub-basins the contracting states need to confront the continuous challenge that eutrophication represents in the area. It is stated by the Ministerial Declaration of 2013 that the plan of reducing N and P to its ecological objectives is to achieve it by 2021.

In Figure 3.6, the seven sub-basins are listed with respect to their MAI, and the GUF appeared in both lists. Although the targets have not been achieved in some of the sub-basins, it was already known that due to the natural processes it was going to take a long time before the eutrophication objectives were reached.



	Nitrogen		Phosphorus	
	MAI (tonnes/year)	Status 2015	MAI (tonnes/year)	Status 2015
Bothnian Bay	57,622	🟩	2,675	🟨
Bothnian Sea	79,372	🟩	2,773	🟩
Baltic Proper	325,000	🟥	7,360	🟥
Gulf of Finland	101,800	🟥	3,600	🟨
Gulf of Riga	88,417	🟨	2,020	🟥
Danish Straits	65,998	🟩	1,601	🟩
Kattegat	74,000	🟩	1,687	🟩

Figure 3.6: Nutrient reduction progress in the sub-basins of the BS (2015) [19]

Anthropogenic activities in the mid-80s lead to HELCOM to recognize eutrophication as a large-scale threat in the BS. The actions in order to reduce 50 % of the nutrients were started in 1988 by the HELCOM Ministerial Declaration [19] and later in 2007 it was identified as one of the main goals by the BSAP.

Since the 80s, the BS has seen a nutrient reduction, and in some sub-basins a strong reduction was seen. For example, in Figure 3.7 it is shown that the level of Phosphorus inputs for today is the same level it was in the 50s.

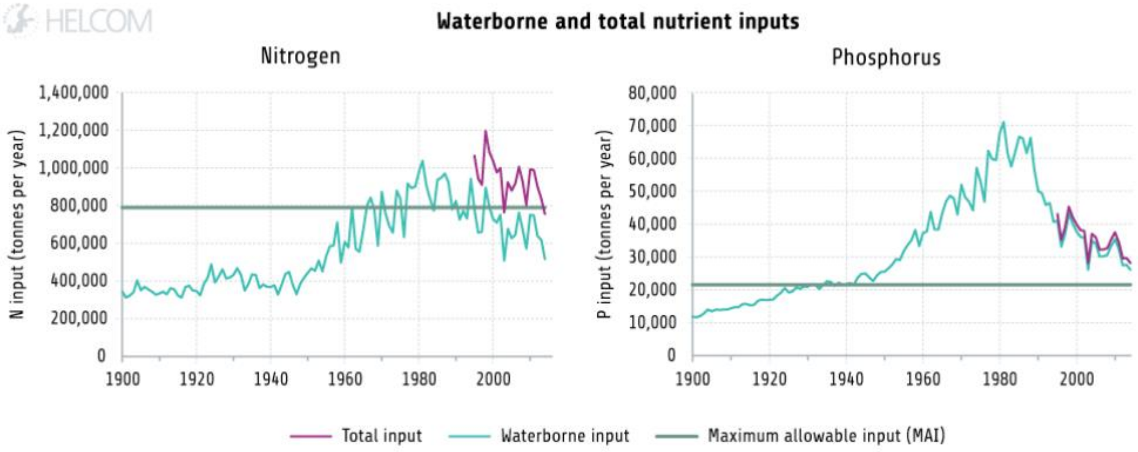


Figure 3.7: Development of total nutrient inputs in the BS, 1900 – 2014 [24]

From Figure 3.7 it is appreciated the long-term trend of the nutrient’s inputs in the BS from 1900, it is clear there has been an improvement throughout the years, unfortunately, the targets are still yet to be met. In Figure 3.8 and Figure 3.9 the trend can be appreciated from a more specific and recent time frame. The BS still has some reductions to achieve in order to reach the established MAI targets for both N and P.

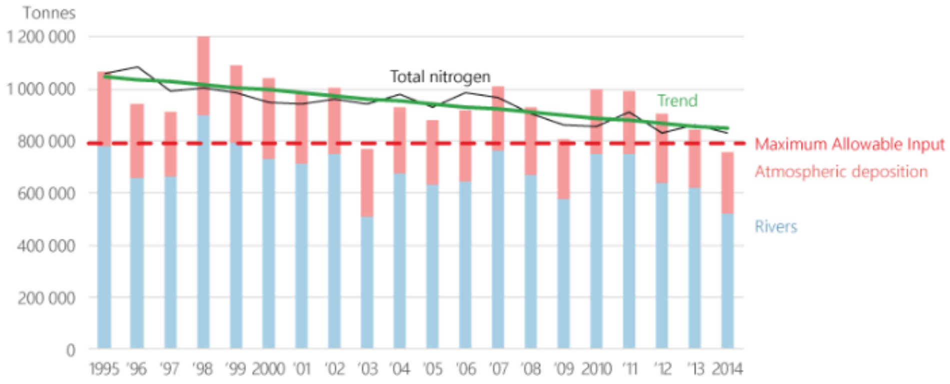


Figure 3.8: TN input to the BS since 1995 to 2014 [30]

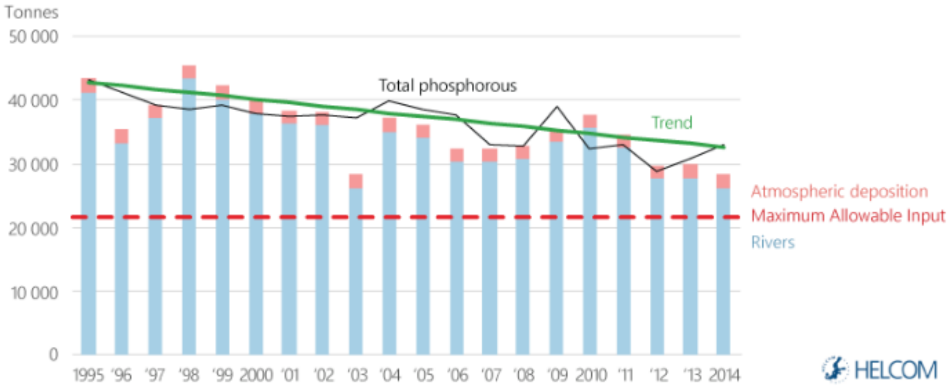


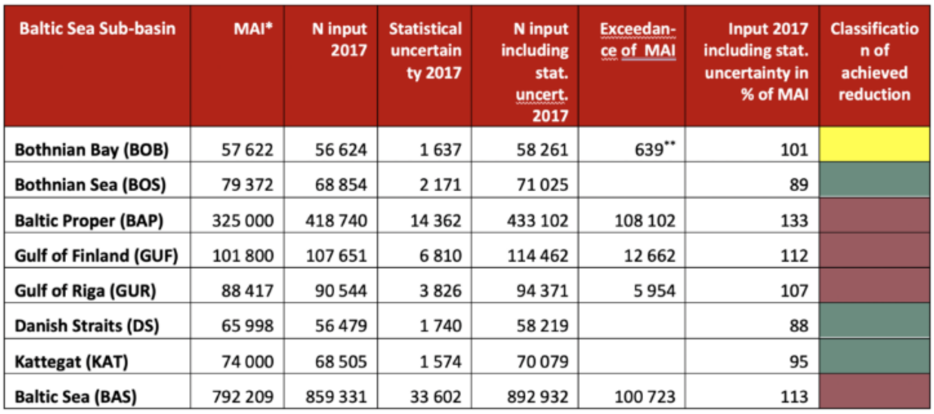
Figure 3.9: TP inputs to the BS since 1995 to 2014 [30]

3.2 Gulf of Finland

The GUF location is in the eastern arm of the BS and it is surrounded by Finland to the north, Estonia to the south, and Russia (Saint Petersburg) to the east. An imaginary line between the Põõsaspea Cape in Estonia and the Hanko Cape in Finland marks its western border [31]. The catchment area of the Gulf of Finland comprises 413,100 km² of which 107,000 km² (26%) belongs to Finland, 276,100 km² (67%) to Russia, 26,400 km² (7%) to Estonia and less than 0.1% (3,600 km²) to Latvia. The GUF is home to one of the seven largest rivers from the BS, this is the Neva River, and along with the Baltic Proper, the GUF has the largest sub-basin catchment area [32].

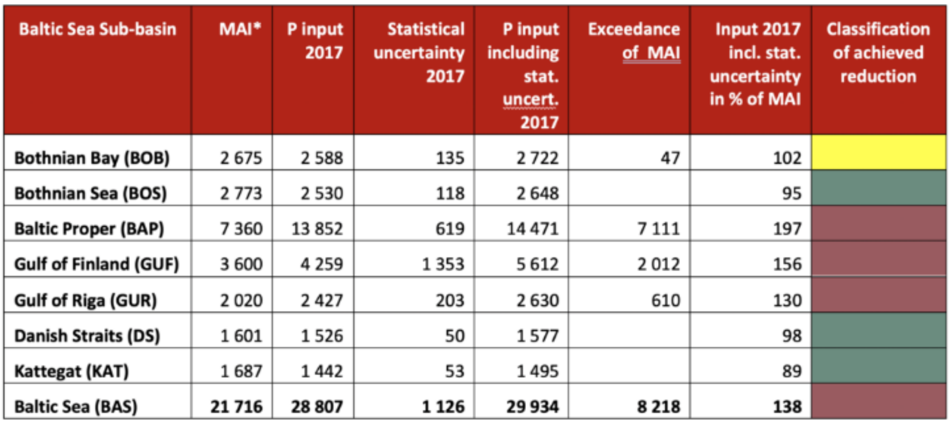
The MAI numbers for the GUF demonstrate the importance of evaluating the changes in nutrients in the area, as the assessment until now has not been the one desired. The total annual nutrients load from rivers depends on the average precipitation in the river basin and in the river flow, and one of the advantages the GUF has is that lakes cover a large section of the drainage basin, a part of the pollution load is retained here [23]. Although there has been a significant deceleration in the eutrophication process in the GUF since the 200s, it is still the most severe environmental problem in the area [33].

The established MAI given by the Copenhagen Ministerial Declaration in 2013 has not been met by the GUF. Based on the data of normalized average input to the sub-basins, the BS has shown an improvement of 14 % for N and 24 % for P between the reference periods of 1997 – 2003 and 2007, and it clearly shows that the GUF must continue to work in order to reach its established MAI [34]. The trend based on the estimate for normalized annual input in the BS during the year 2017, which includes the statistical uncertainty and the remaining reduction needed to achieve the MAI, is the following:



Baltic Sea Sub-basin	MAI*	N input 2017	Statistical uncertainty 2017	N input including stat. uncert. 2017	Exceedance of MAI	Input 2017 including stat. uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay (BOB)	57 622	56 624	1 637	58 261	639**	101	🟨
Bothnian Sea (BOS)	79 372	68 854	2 171	71 025		89	🟩
Baltic Proper (BAP)	325 000	418 740	14 362	433 102	108 102	133	🟥
Gulf of Finland (GUF)	101 800	107 651	6 810	114 462	12 662	112	🟥
Gulf of Riga (GUR)	88 417	90 544	3 826	94 371	5 954	107	🟥
Danish Straits (DS)	65 998	56 479	1 740	58 219		88	🟩
Kattegat (KAT)	74 000	68 505	1 574	70 079		95	🟩
Baltic Sea (BAS)	792 209	859 331	33 602	892 932	100 723	113	🟥

Figure 3.10: Normalized annual inputs for N for the BS in 2017 [34]



Baltic Sea Sub-basin	MAI*	P input 2017	Statistical uncertainty 2017	P input including stat. uncert. 2017	Exceedance of MAI	Input 2017 incl. stat. uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay (BOB)	2 675	2 588	135	2 722	47	102	🟨
Bothnian Sea (BOS)	2 773	2 530	118	2 648		95	🟩
Baltic Proper (BAP)	7 360	13 852	619	14 471	7 111	197	🟥
Gulf of Finland (GUF)	3 600	4 259	1 353	5 612	2 012	156	🟥
Gulf of Riga (GUR)	2 020	2 427	203	2 630	610	130	🟥
Danish Straits (DS)	1 601	1 526	50	1 577		98	🟩
Kattegat (KAT)	1 687	1 442	53	1 495		89	🟩
Baltic Sea (BAS)	**21 716**	**28 807**	**1 126**	**29 934**	**8 218**	**138**	🟥

Figure 3.11: Normalized annual inputs for P for the BS in 2017 [34]

Classification of achieving MAI: green= fulfilled, yellow= fulfilment is not determined due to statistical uncertainty, and red=MAI not fulfilled.

In Figures 3.10 and Figure 3.11 it can be appreciated which of the sub-basins have not fulfilled their MAI targets. The Bothnian Bay, although their inputs for N and P have been below their MAI targets, it cannot be considered as fulfilled because of the statistical uncertainty. The GUF appears as failed in both tables (N and P), but its deceleration in eutrophication is seen when comparing the values for 2017 and the values from before. In the reference periods of 1997 – 2003 (Figure 3.4) its N input was 116,252 tonnes and for P it was 7,509 tonnes, with a needed reduction of 14,452 tonnes and 3, 909 tonnes respectively. For the year 2017, the nutrient inputs were 107, 651 tonnes for N and 4,259 for P with MAI exceedance of 12,662 tonnes for N and 2,012 tonnes for P. An overall progress has been done, but nutrient reduction must still be a priority in order to achieve the MAI and consequently a good environmental status.

Furthermore, as it was mentioned before, most of the nutrients entering the BS come from rivers and there are large proportion differences between the natural background inputs from the different sub-basins in the BS. As mentioned before, the natural background loads of N and P constitutes one third of the total load inputs in the BS and the largest proportion of natural loads occur in the GUF with 67.7 % for N and 58.6 % for P [29].

For the entire BS, the TN inputs have fallen during the recorded period and the direct point-sources have experience the biggest change. The changes in the main pathways for TN for the GUF can be seen in Figure 3.12.

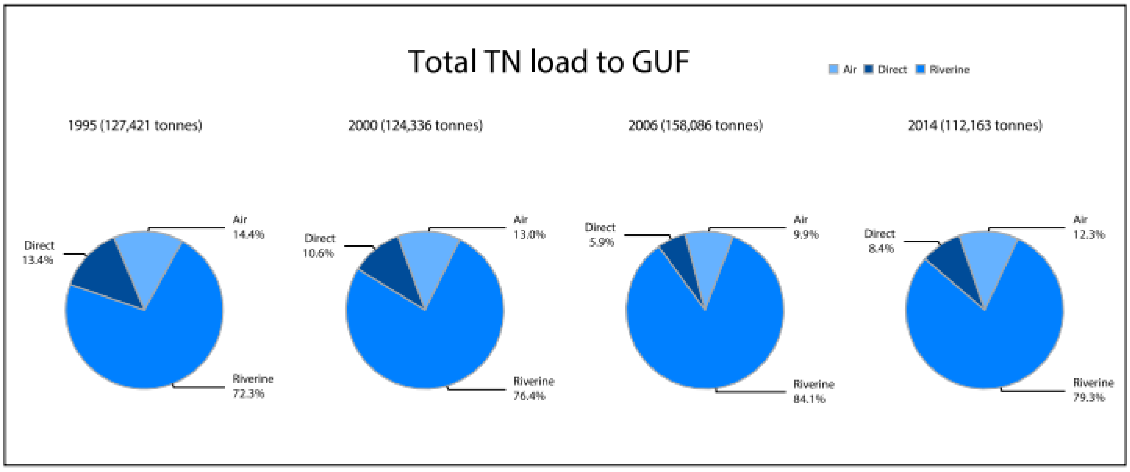


Figure 3.12: Sources of N inputs in the GUF through different years [29]

The overall pattern from the different pathways for both N and P is different, nevertheless the average inputs for both has been reduced over the recorded time frame. The changes in the main pathways for TP for the GUF can be seen in Figure 3.13.

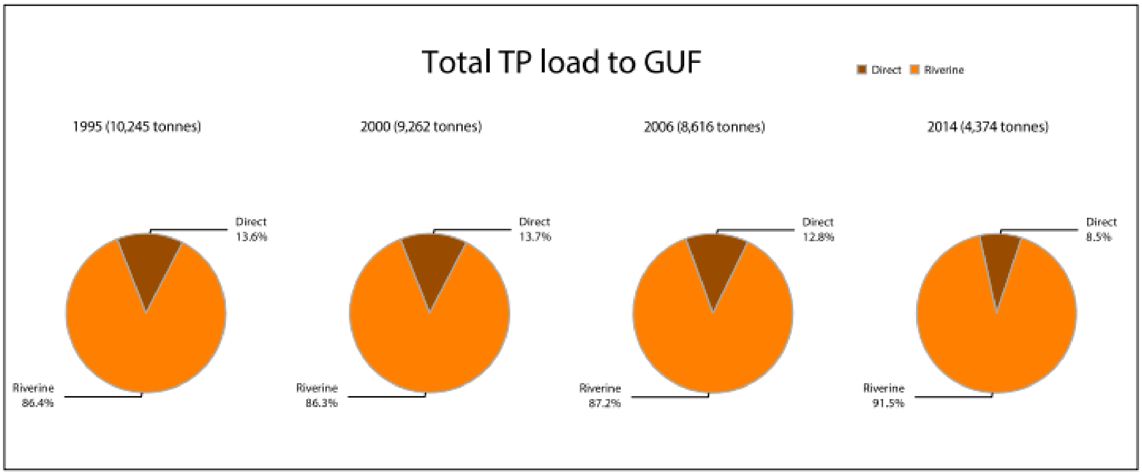


Figure 3.13 Sources of P inputs in the GUF through different years [29]

3.3 Estonia

Estonia is in northeastern Europe; it is the northernmost country of the Baltic states. Estonia juts out to the BS through the GUF and Gulf of Riga, which surrounds the Estonian territory to the north and west respectively. To the east Estonia is bounded by Russia, and to the south with Latvia. Estonia’s land border is composed of 645 km² to which half of it is running along water bodies. At the beginning of the year of 2021, the population in Estonia was 1,329,450 inhabitants, this number includes citizens and foreign nationals living in Estonia [35].

Estonia, in terms of area, it is like that of The Netherlands, but having a population of about 10 times smaller. The country has an area of about 45,277 km² and it includes some 1,500 islands and islets.

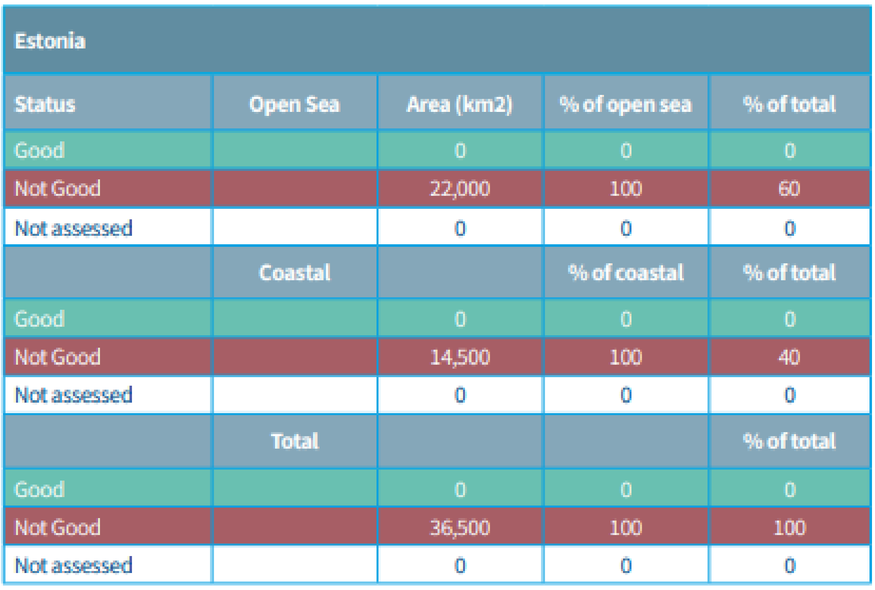
Figure 3.14: Estonian geographical map [36]

Land cover and land use in the Estonian territory (from 2012) in the BS catchment area is 58 % forests, 21 % cultivated area, 5 % surface waters, 2 % urban areas, and 14 % others [18]. About 60 % belongs to the catchment area of the GUF, about 37 % belongs to the catchment area of the Gulf of Riga, and about 3 % belong to the catchment area of the Baltic Proper (the western parts of the islands Saarema and Hiiumaa) [32].

For the GUF, Estonia has a population density of 48 inhabitants per km² and the length of the Estonian part of the GUF is of 600 km², excluding the islands. The southern Estonia lies in the catchment area of the lake Pepsi which discharges in the GUF via the Narva River.

Estonia does not show a good result when eutrophication status is assessed, and because inputs of N and P have been increasing for a long time in the BS, it is of importance to analyze the current status and work towards the betterment of it.

An overall assessment of the proportion of area below good status regarding eutrophication was calculated in the contracting states of the BS using the HELCOM shapefile. This was done by using the ArcGIS 'Calculate Geometry' function and calculating sum of area by "Status". This assessment was done by assessing the area and proportion by status in open waters and coastal waters. The result of this assessment for Estonia can be seen in Figure 3.15.



Estonia				
Status	**Open Sea**	**Area (km2)**	**% of open sea**	**% of total**
Good		0	0	0
Not Good		22,000	100	60
Not assessed		0	0	0
	Coastal		**% of coastal**	**% of total**
Good		0	0	0
Not Good		14,500	100	40
Not assessed		0	0	0
	Total			**% of total**
Good		0	0	0
Not Good		36,500	100	100
Not assessed		0	0	0

Figure 3.15: Thematic assessment of eutrophication in Estonia, 2011 - 2016 [19]

This integrated assessment had a result of 86 % of the coastal waters being in good status (5 % was not assessed) and 100 % of the open sea waters were not in good status [19]. For Estonia, the result was the same for both cases, 100 % were in not a good status.

Discharges from point sources in the BS catchment area have a significant impact in the state of its waters. Untreated wastewater discharge into inland surface was approximately 340 million m³/a in the year 2000. From this figure, more that 270 million m³/a was discharged from MWWTPs. The vast majority was from Russia, accounting for 250 million m³/a, and the remaining 20 million m³/a of untreated municipal wastewater were discharged from Latvia, Lithuania, and Estonia [32]. These untreated waters were discharged into the Baltic Proper, Gulf of Riga and GUF. None of the other contract states discharged into inland waters.

The reduction of nutrient inputs has been implemented in different periods for each country, this can become evident when looking at the status of the different countries throughout the years. Countries like Denmark, Germany, Sweden, and Finland had started implementing measure to reduce the impact of their point sources some time before the HELCOM measures were starting to be implemented. For this reason, these countries can now focus on the reduction of diffuse sources (focusing more in agriculture) instead of focusing in the improvement of their wastewater treatment plants, as this can end up with relatively low reduction and high prices.

In Estonia, the levels of N and P have dropped 71 % and 79 %, respectively. These numbers are mainly due to the decrease in industrial and agricultural production (beginning in the 1990s), but in recent years, the load reduction had accelerated due to the number of wastewater treatment plants that had been built and renovated. By 2010, an average of 85 – 95 % of pollutants were reduced from the wastewater treatment and in 2007, 99 % of the water that had to be treated, was treated [37].

Connectivity to WWTPs have seen an improvement in some countries, especially in Lithuania, Russia, and Poland. This is of great importance as it has been seen reduction in the P load from scattered dwellings, and consequently, decreasing the amount to diffuse sources inputs into the rivers. In Estonia, there has been an increase of 10 % from 2004 to 2014 of the population connected to urban WWTPs. About 82 % of the population is connected to the public urban sewage system in Estonia [18], and it must continue to work in reductions not only focusing in its wastewater, but also in its agricultural sector.

Eutrophication in the GUF is predominately caused by the riverine nutrient inputs, and in Estonia, diffuse sources (mainly agriculture) are the main contributors. The natural background constitutes to a 33.5 % for N and 21.2 % for P. These numbers are much lower when compared to those of diffuse sources which are 64.1 % for N and 75 for % for P. Point sources are less of a focus as they just contribute 2.4 % for N and 3.8 % for P.

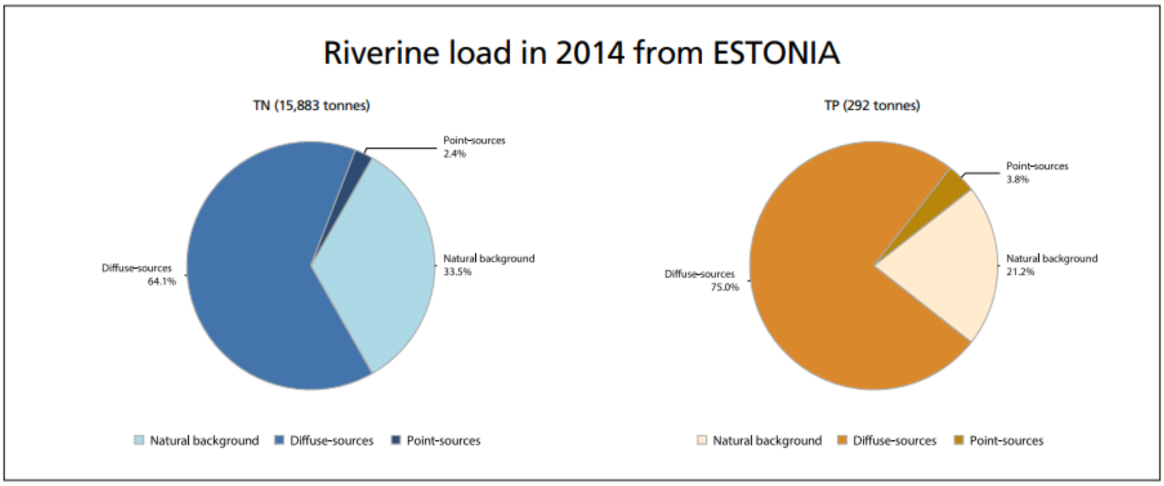


Figure 3.16: Sources of riverine loads in Estonia in 2014 [29]

From 1995 to 2014, the riverine TN input changed from 80.2 % to 87.5 % in Estonia, this increment was taken from the direct sources which passed from being 9.6 % to 2.2 % in that same period (Figure 3.17).

The sources of P had also seen an increment in the riverine input through the years, although not as big as in the N inputs. For TP inputs, there was an increment of 4.4 % from 1995 to 2014, and from direct sources it reduced from 11.8 % to 7.4 % in that same period (Figure 3.18).

These reductions are the result of the pollutants that are now routed to treatment plants in recent years in connection with the city sewage. Adding to this, the renovation of several treatment plants: Kohtla-Järve, Narva, Tartu, Valga, Põltsamaa, Otepää, Kohila, Jüri, and Märjamaa [37]. To understand the real impact of these renovations an example can be mentioned: The completion of the Kösti treatment plant resulted in Viljandi's town untreated wastewater no longer being released directly into the environment.

It is important to consider that only MWWTPs larger than 2,000 PE were reported in Estonia for these results.

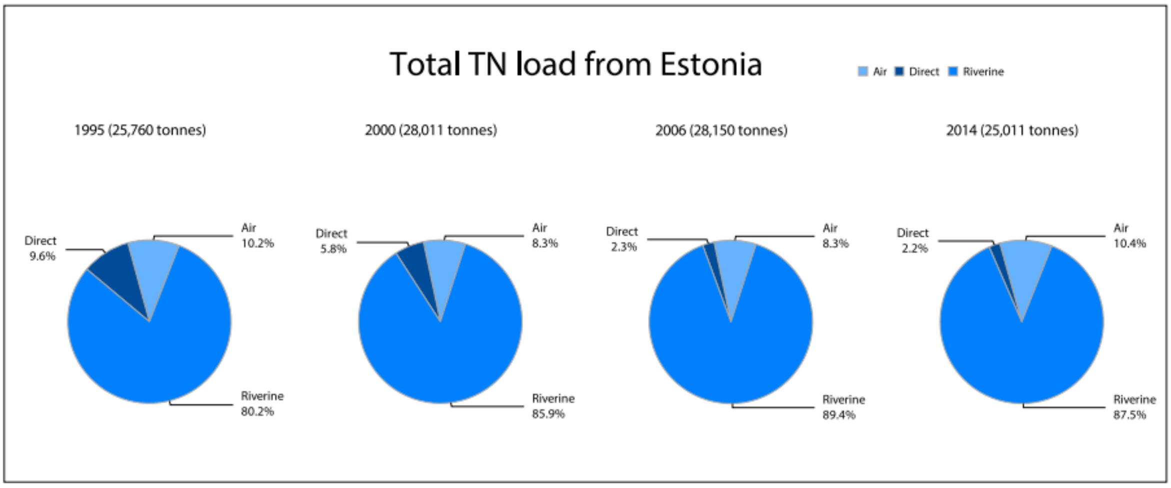


Figure 3.17: Sources of TN inputs in Estonia for the different years [29]

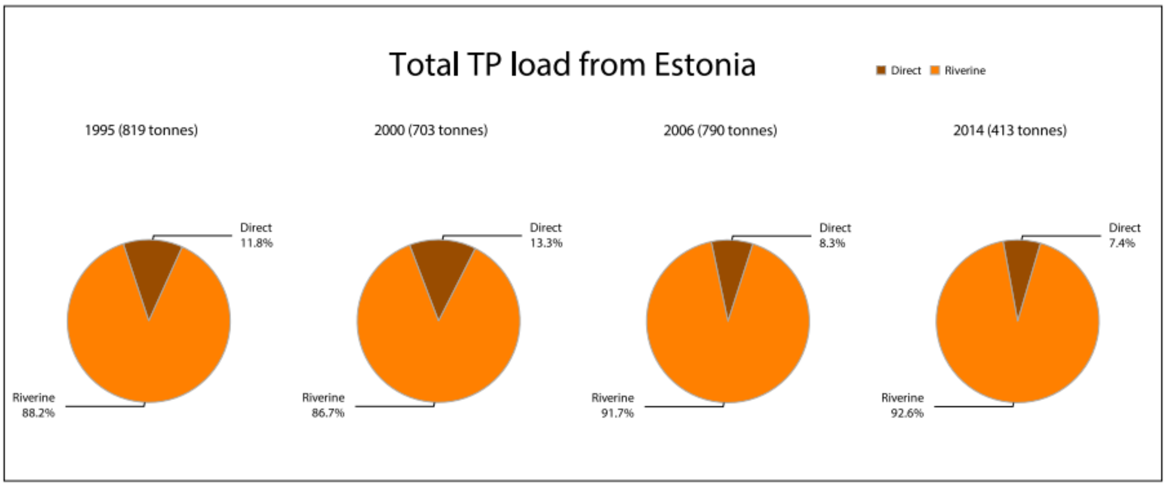


Figure 3.18: Sources of TP inputs in Estonia for the different years [29]

4 DATA SOURCES AND METHODOLOGY

This thesis establishes the TMDL for N and P in some rivers of Estonia. Water quality modeling was performed in order to identify the current water quality conditions of the rivers by reflecting the total pollutant loading in each of the rivers. The TMDL will reflect the current state and determine the needed load reductions the water body must take.

Analyzing the state of these Estonian rivers is important as N and P enter streams directly from the wastewater-treatment plants (point sources) or through agricultural processes and urban runoff (nonpoint sources), which consequently end up in the GUF contributing to eutrophication.

For the reason stated above, the TMDL model was developed to address the nutrients in the rivers which are the main cause of eutrophication in the area: Nitrogen and Phosphorus.

4.1 Selected rivers and map

The 13 rivers studied in this thesis which discharge to the GUF are the following: Pühajõgi River, Purtse River, Kunda River, Selja River, Loobu River, Valgejõgi River, Pudisoo River, Jägala River, Pirita River, Vääna River, Keila River, Vihterpalu River, and Narva River. Kasari River discharges into the Gulf of Riga.

Pärnu River also discharges to the GUF, given the fact that this river has its own DAML study, it was not included in this study.

The estimate location of these rivers in Estonia can be seen from Figure 4.1. This map was developed with details obtained from the Interactive Water Monitoring Map from the National weather Service of Estonia. The map of the watercourses was combined with the hydrometric stations map and the result was the representation of the rivers studied in this thesis with their respective hydrological station. Each river is represented by a blue line and numbered; each number represents a specific river which name is detailed below the map representation.

Figure 4.1: Rivers representation with their hydrolocial stations on Estonian map

Hydrometric stations

1	2	3	4	5	6	7
Kasari	Vihterpalu	Keila	Vääna	Pirita	Jägala	Pudisoo
8	**9**	**10**	**11**	**12**	**13**	**14**
Valgejõg	Loobu	Selja	Kunda	Purtse	Pühajõgi	Narva

4.2 Data sources and availability

Hydrological monitoring data of long-term daily flows of any river in Estonia is readily available and was acquired from the Historical Observation Data bank in the State Weather Service of Estonia.

The first river to be measured on its water level was the Emajõgi River in 1866, and more regular measurements began in the spring of 1867. In that same river in the year 1922, measurements of the daily flow stared, and during that same decade it started in other rivers in Estonia [38] . In 2019, the hydrometric network included 55 water level stations on rivers, 54 of which calculated runoff, and 6 water level stations on lakes-reservoirs [39].

Long term daily flows of any river can be obtained from the Historical Observation Data, and for the purpose of this thesis, daily flows from the years 1993 to 2019 were used. In some of the rivers, data was missing for some years and the TMDL process was made for the years available from the same period (1993 – 2019).

Historical nutrient loads for the Estonian rivers were gathered from the report: SISEVEEKOGUDE JA MERE VEENORMIDE VAHELISED SEOSED JA VÕRRELDAVUS (translation to English: RELATIONSHIP AND COMPARABILITY BETWEEN INLAND WATERWAYS AND MARINE WATER STANDARDS) where raw data was gathered from the Estonian Environmental Agency.

4.3 Methodology

In order to provide a TMDL study for the rivers, the method requires both: daily stream flow of the rivers and the pollutant concentration for each of the rivers.

Gathering the record of the historical daily flow through the period from where the study is focused, 1993 – 2019, provides the necessary information to develop the FDC. This curve represents the percentage of time during which a specified flow has been met or exceeded.

For the LDC, load targets had to be established in order to deduce if the river is in a good or bad status. For the purpose of this thesis, the targets are: 2,0 mg/l and 1,5 mg/l for N and 0,08 mg/l and 0,06 mg/l for P.

The LDC must provide the observed load, and these are obtained by multiplying the sampled TN concentration and TP concentration for each river by the instantaneous flow that is associated (by date) with the recorded sample. This curve represents the exceedance of loads with respect to the established targets.

4.4 Gathered data

By gathering the load concentration for each of the rivers throughout the study period (1993 – 2019) it was possible to compile a table representing the values using the logic of the Box and Whiskers plot.

The results for TN and TP can be seen in Table 4.1 and Table 4.2, respectively. In the following tables, the "max" represents the upper quartile (0,75 percentile), the "mean" represents the 0,5 percentile, and the "min" represents the lower quartile (0,25 percentile). The Box and Whiskers plot for each of the rivers will be displayed in the description of the rivers in the following chapter for a better view of its state.

These long-term values can be compared to the values obtained from a report where the study was conducted for more recent years, 2009 – 2018 (Table 4.3 and Table 4.4).

For an easy view on the state of the concentration loads of each river during the specific period of this study, the mean is used as the factor to deduce if the loads for each of the studied rivers are under the established limit or not. The highest limit for both TN and TP is used (2,0 mg/l and 0,08 mg/l) for the purpose of these representations. The asterisk besides Narva River means that different criterion is applied there: 0,7 mg/l for TN and 0,06 mg/l for TP.

The blue color on the number means that the value is equal or lower than the established limit, and the red color means that it is higher and therefore needs reduction.

Table 4.1: Mean content of TN, 1993 - 2019

TN (mg/l)	**Narva***	**Pühajõgi**	**Purtse**	**Kunda**	**Selja**	**Loobu**	**Valgejõgi**
0,9 percentile	0,8	1,7	2,2	3,2	7,1	4,6	2,3
Max	2,1	5,3	11,2	9,5	13,0	7,8	3,9
Mean	0,6	1,5	1,7	2,3	5,7	3,7	1,9
Min	0.1	0,5	0,4	0,4	2,2	0,6	0,3
0,1 percentile	0,5	1,1	1,3	1,8	4,8	2,4	1,5
TN (mg/l)	**Pudisoo**	**Jägala**	**Pirita**	**Vääna**	**Keila**	**Vihterpalu**	**Kasari**
0,9 percentile	0,2	0,7	0,4	0,5	0,6	0,8	0,4
Max	0,8	1,8	2,0	2,7	2,5	1,5	1,4
Mean	1,3	2,5	3,0	3,8	3,3	2,0	2,1
Min	1,6	3,3	3,8	4,8	4,1	2,7	2,8
0,1 percentile	2,8	5,4	8,1	13,6	6,8	5,6	5,6

Table 4.2: Mean content of TP, 1993 - 2019

TP (mg/l)	**Narva***	**Pühajõgi**	**Purtse**	**Kunda**	**Selja**	**Loobu**	**Valgejõgi**
0,9 percentile	0.05	0,06	0,04	0,05	0,09	0,05	0,05
Max	0.19	0,38	1,80	0,20	0,46	0,15	0,21
Mean	0.04	0,05	0,02	0,03	0,06	0,04	0,04
Min	0.01	0,01	0,01	0,01	0,01	0,02	0,01
0,1 percentile	0.03	0,03	0,02	0,03	0,05	0,03	0,03
TP (mg/l)	**Pudisoo**	**Jägala**	**Pirita**	**Vääna**	**Keila**	**Vihterpalu**	**Kasari**
0,9 percentile	0,04	0,02	0,01	0,05	0,02	0,02	0,00
Max	0,07	0,04	0,04	0,09	0,05	0,03	0,03
Mean	0,08	0,04	0,05	0,10	0,07	0,04	0,04
Min	0,10	0,05	0,06	0,13	0,11	0,05	0,05
0,1 percentile	0,34	0,67	0,03	0,33	0,27	0,12	0,26

Table 4.3: Mean content of TN, 2009 – 2019 [40]

TN (mg/l)	**Narva***	**Pühajõgi**	**Purtse**	**Kunda**	**Selja**	**Loobu**	**Valgejõgi**
0,9 percentile	1	2,1	2,1	3,8	8	5,4	3,0
Max	2,1	5,3	3,1	8,2	13	7,8	3,7
Mean	0,7	1,5	1,4	2,6	5,8	3,4	2,0
Min	0,1	0,5	0,4	0,4	1	0,6	0,7
0,1 percentile	0,5	0,8	0,7	1,5	3,4	1,3	1,1
TN (mg/l)	**Pudisoo**	**Jägala**	**Pirita**	**Vääna**	**Keila**	**Vihterpalu**	**Kasari**
0,9 percentile	1,9	3,9	4,5	4,6	4,9	3,1	3,3
Max	2,8	5,4	7,4	8,1	7	5,64	5,6
Mean	1,3	2,5	2,9	2,9	3,2	2,1	2,1
Min	0,2	0,7	0,4	0,5	0,7	0,8	0,5
0,1 percentile	0,5	1,2	0,9	1,3	1,4	1,2	0,9

Table 4.4: Mean content of TP, 2009 – 2019 [40]

TP (mg/l)	**Narva***	**Pühajõgi**	**Purtse**	**Kunda**	**Selja**	**Loobu**	**Valgejõgi**
0,9 percentile	0,05	0,08	0,04	0,05	0,11	0,06	0,06
Max	0,13	0,38	0,13	0,2	0,46	0,15	0,21
Mean	0,03	0,05	0,03	0,04	0,07	0,04	0,04
Min	0,01	0,01	0,01	0,01	0,01	0,02	0,01
0,1 percentile	0,02	0,02	0,01	0,02	0,03	0,02	0,02
TP (mg/l)	**Pudisoo**	**Jägala**	**Pirita**	**Vääna**	**Keila**	**Vihterpalu**	**Kasari**
0,9 percentile	0,13	0,06	0,07	0,16	0,12	0,07	0,06
Max	0,28	0,67	0,26	0,27	0,17	0,1	0,11
Mean	0,09	0,05	0,05	0,11	0,08	0,05	0,04
Min	0,04	0,02	0,02	0,05	0,04	0,02	0
0,1 percentile	0,06	0,03	0,03	0,07	0,05	0,03	0,02

5 TMDL - RIVERS OF ESTONIA

The calculation of impaired segments is one of the first steps when applying the TMDL process. The loading capacity provides a reference of the amount of loading that a water body can receive before it overpasses the water quality standards.

For this thesis, the target loads were established to be 2,0 mg/l and 1.5 mg/l for TN and 0.08 mg/l and 0.06 mg/l for TP. The stream loads for TN and TP are expressed in tonnes per day, and to convert these values it was necessary to do some calculations which are represented in Table 5.1.

The loading capacity for TN and TP, using the Kunda River TN as an example, are represented in Figure 5.1. This graph (Figure 5.1) is derived directly from the established criteria mentioned before, and LDC was done using the calculations described in Table 5.1 across the daily flows. Same calculations apply for TP.

Table 5.1: Calculation for TN and TP loads

Load (*tonnes per day*) = **Flow** (*m3*) * **Concentration** (*mg/L*) * **Factor**			
multiply by 86,400 *to convert*	seconds per day	→	m3/day
multiply by 1,000 *to convert*	liters	→	L/day
multiply by 0.000000001 *to convert*	mg	→	tonnes
multiply by **0.0864** *to convert*	**(m3/s)*(mg/L)**	→	**tonnes/day**

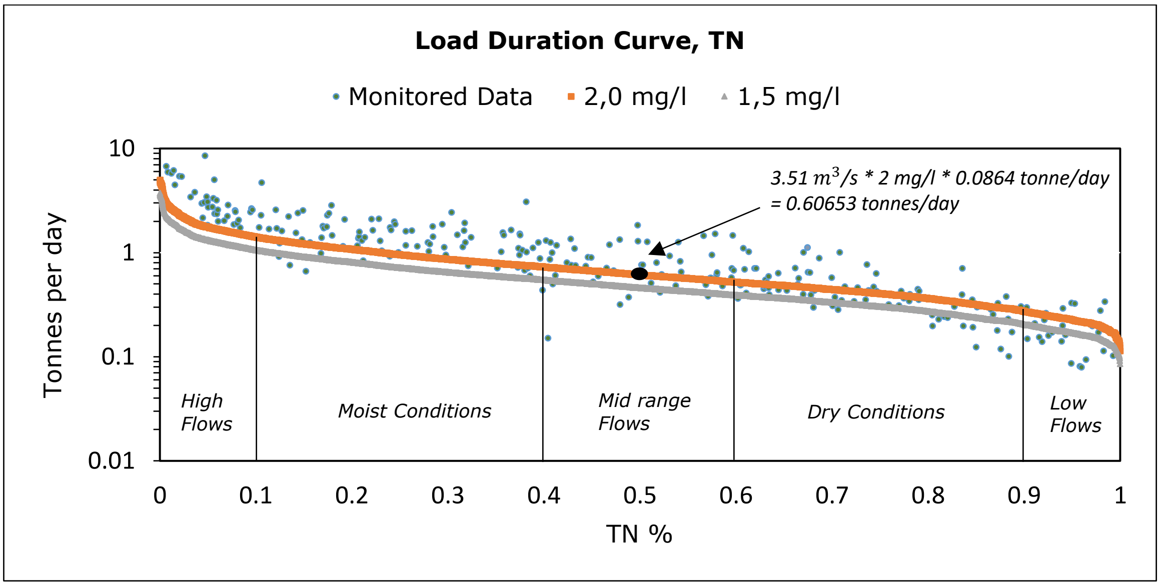


Figure 5.1: TN loading capacity calculation explanation, Kunda River

5.1 Kasari River

The Kasari River is a river in western Estonia, and it drains to the east of the Matsalu Bay (Gulf of Riga). The delta area of the Kasari River is part of the Matsalu nature reserve, and it holds the 4th place of Estonian rivers for both its length and its amount of water [41].

The river has a length of 112 km and with its additional branches the length of the river extends to 134,5 km [42]. The river has an average flow of 25,45 m³/s.

The total catchment area is of the river is 3213,1 km² and the catchment area of the monitoring station is of 2640 km². The land is mostly covered by forest as it covers 61 %, and it almost double the second in position which is agricultural land with 34 % [40].

Monitored data

For Kasari River, the complete data from the years 1993 – 2019 was available.

The results of the monitored loads data during that period provided the following information: For N, the minimum recorded data was 0,37 mg/l, a maximum of 5,6 mg/l, and a mean value of 2,1 mg/l. For P, the minimum value recorded was of 0,002 mg/l, a maximum value of 0,26 mg/l, and a mean value of 0,04. These numbers are represented in Figure 5.2.

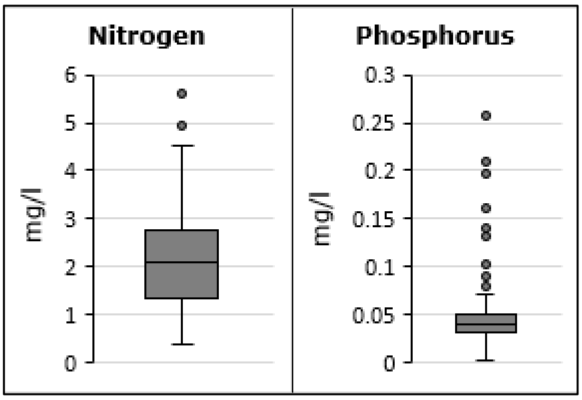


Figure 5.2: Mean content of N and P for Kasari River

When comparing these long-term means to the results given from the period 2009 - 2019 represented in Tables 4.3 and 4.3, it is clear that the Kasari River has kept its loads concentration stable for both N and P as they provide the same means as the long-term data.

In a more specific date frame, when comparing the monitored values in 2018 to those of the long-term values it is seen that there is an improvement for both TN and TP as the recorded data were: 2,0 mg/l and 0,03 mg/l for TN and TP, respectively [43].

The highest flows occur during the month of April as seen in the long-term daily flow monthly average in Figure 5.3.

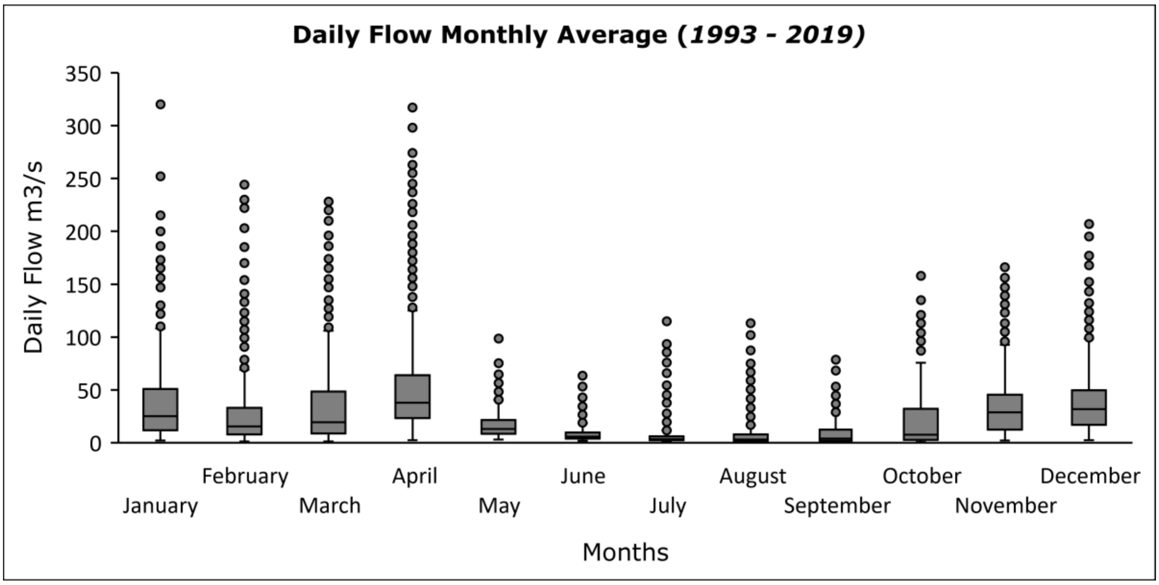


Figure 5.3: Daily flow monthly average, Kasari River

In Figure 5.4, the LDC for TN shows that that the exceedance loads occur throughout all the seasonal variations, which can lead to focus on a continuous point source. Adding to this, there is a significant increment during the moist conditions period which extends to the high flows. It is importance to focus on the values monitored during the high flows, as almost all the monitored data is exceeding the established limit, even when considering the lowest of the established limits (1,5 mg/l). This can be consequence to the source's areas typical during this seasonal period. Agricultural sector constitutes 34 % of the total catchment area, meaning that in April, the moist conditions can reflect a more saturated soil conditions and therefore the flows exerted from the sources of cultivated land will have more influence on the water quality of the river.

Point sources have an important impact in the water quality of Kasari River, in terms of TN, the mean point sources load for the year's period of 2015 – 2019 was of 14,4 mg/l which is extremely high in comparison with the established limit of 2 mg/l. For TP, the input value is also high but in compliance with the highest target value, with a mean point sources load of 0,08 mg/l [40].

TP does not possess a threat to the water quality of the Kasari River. In Figure 5.5 it is shown that the monitored values are mostly under compliance with the established limits, even with the lowest limit of 0,06 m/l.

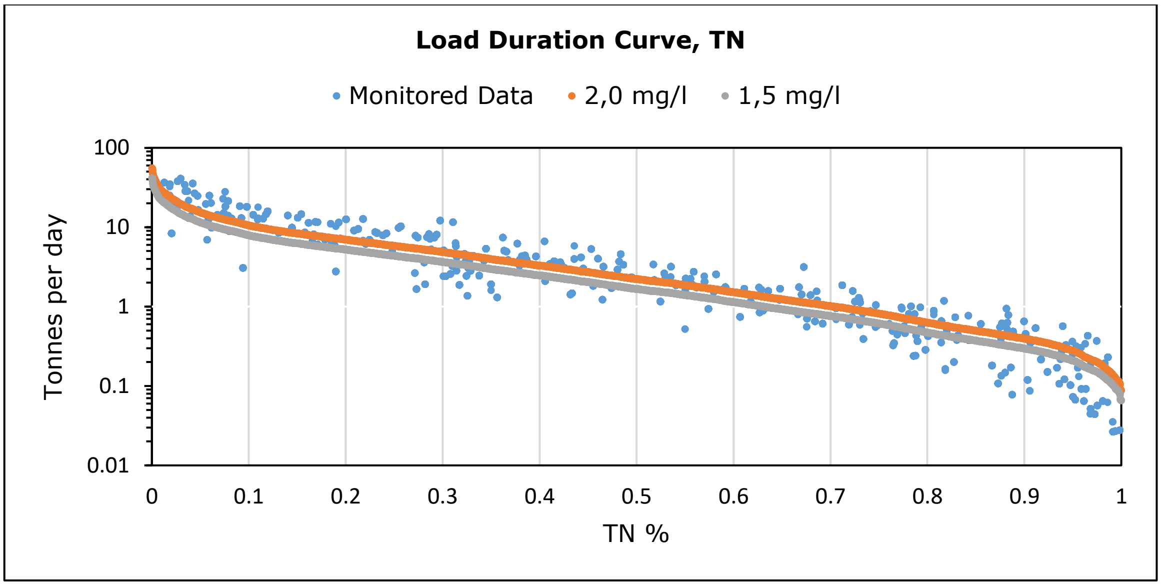


Figure 5.4: LDC for TN, Kasari River

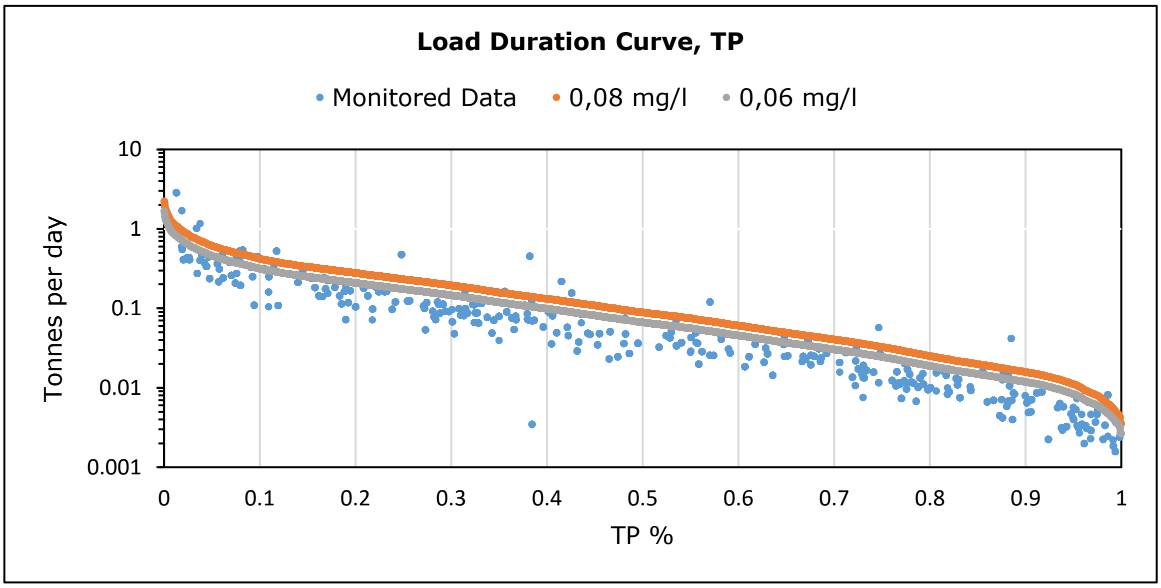


Figure 5.5: LDC for TP, Kasari River

5.2 Vihterpalu River

The Vihterpalu River is in Harju county and Lääne county and it flows into the strait of Kurkse.

It has a length of 54,1 km including its additional branches [42], and an average flow of 4,48 m³/s.

The total catchment area of the rivers is of 381.1 km² and the catchment area of the monitoring station is of 474 km². The area is composed mostly of forest as it covers 72 % of the land. The agricultural land is composed by 17 % and the wetland covers 10,6 % of the total land [40].

Monitored data

The complete data for the period 1993 – 2019 was available for the Vihterpalu River.

The monitored input load values gathered during this period resulted in the following: The minimum value for N was 0,75 mg/l, the maximum value was 5,6 mg/l, and a mean value of 2,0 mg/l. For P, the minimum value was 0,02 mg/l, the maximum value was 0,01 mg/l, and the mean value was 0,04 mg/l. These monitored values are represented in Figure 5.6.

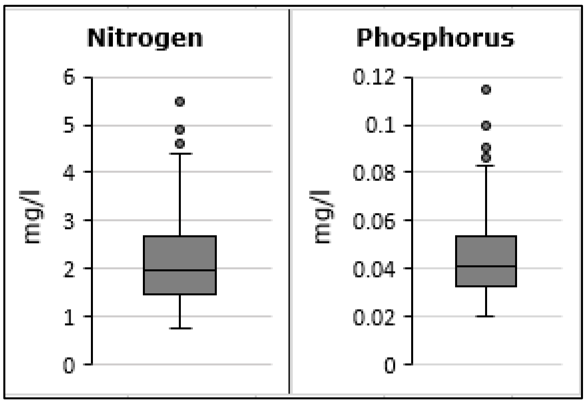


Figure 5.6: Mean content of N and P for Vihterpalu River

The input values for N and P mean value have increased when comparing the mean values of the monitored period of 1993 – 2019 in Tables 4.3 and 4.4 with the long-term average. The value for N in the most recent period is 2,1 mg/l, meaning that it is above the established limit of 2,0 mg/l (different case then the long-term period that is in compliance with the limit as it is 2,0 mg/l). In the case of P, the mean value had increased to 0,05 mg/l [40], and this value is still in compliance with the establish limit, even with the lowest limit of 0,06 mg/l.

These monitored values also change when we compare them to the monitored data for the year 2018. The value for N decreases to 1,9 mg/l and the value for P increases to 0,06 mg/l [43], and in these cases, the values are in compliance with the highest target values of 2,0 mg/l for N and 0,06 mg/l for P, but in the case of TN it shows exceedance with the lowest target value of 1,5 mg/l.

The highest flows occur during the month of April as seen in the long-term daily flow monthly average in Figure 5.7.

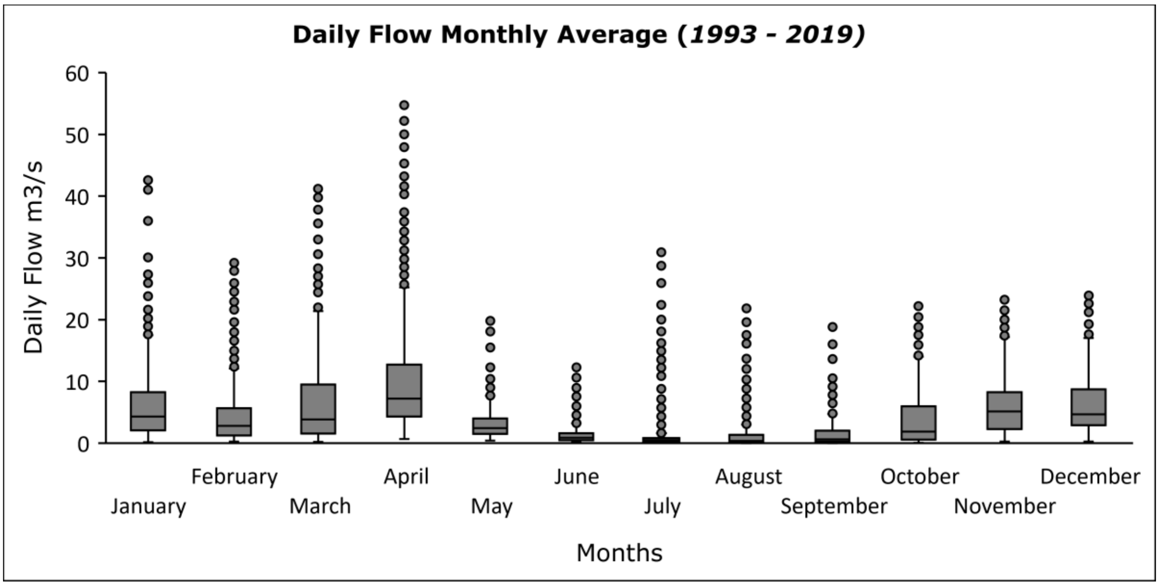


Figure 5.7: Daily flow monthly average, Vihterpalu River

Exceedance in load inputs for TN can be seen throughout all the seasonal variations (Figure 5.8), which can lead to assume there are point sources that are discharging in the river throughout the year. But when analyzing the mean value of the point sources, this value does not show it is the cause of the exceedance in N, as the mean values for point sources during the period of 2015 – 2019 are:0,012 mg/l for TN and 0,02 for TP [40]. Both values are under the established targets.

From the LDC of TN, the monitored data shows that most of the exceedance occurs at high flows. When considering 2,0 mg/l as the limit, almost all monitored data are in exceedance during high flows, and it shows the opposite for the low flows where most the values are below the 2,0 mg/l target. It is different when considering 1,5 mg/l as the target value, as even at low flows it shows that most of the monitored data values are in exceedance in comparison with the limit.

In terms of TP, the monitored data is in compliance with the established data even when considering the lowest established limit (0,06 mg/l). Therefore, TP is not a problem for the Vihterpalu River.

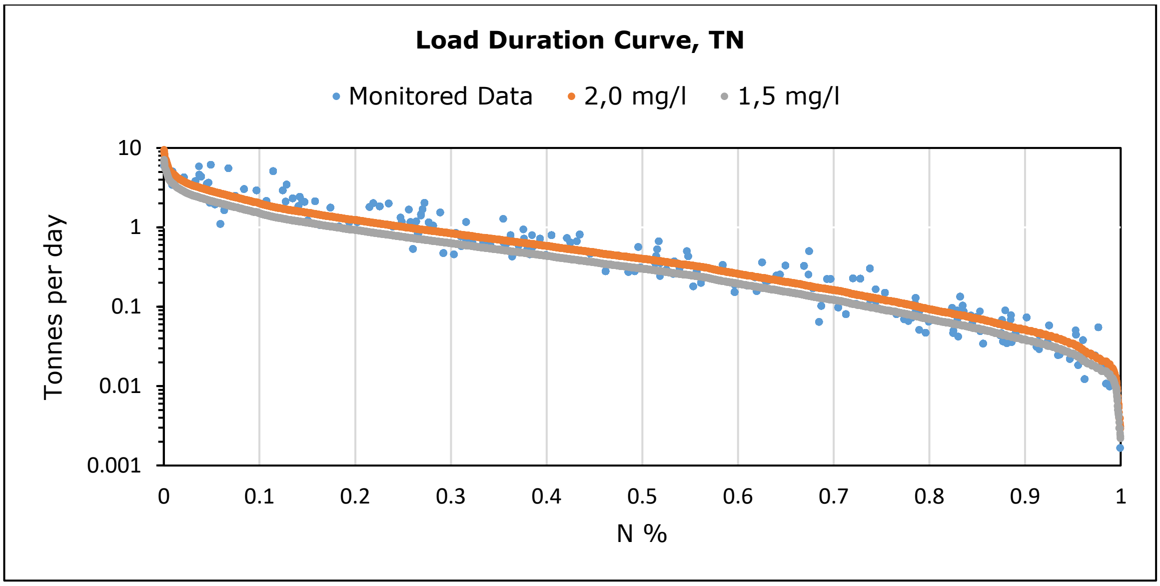


Figure 5.8: LDC for TN, Vihterpalu River

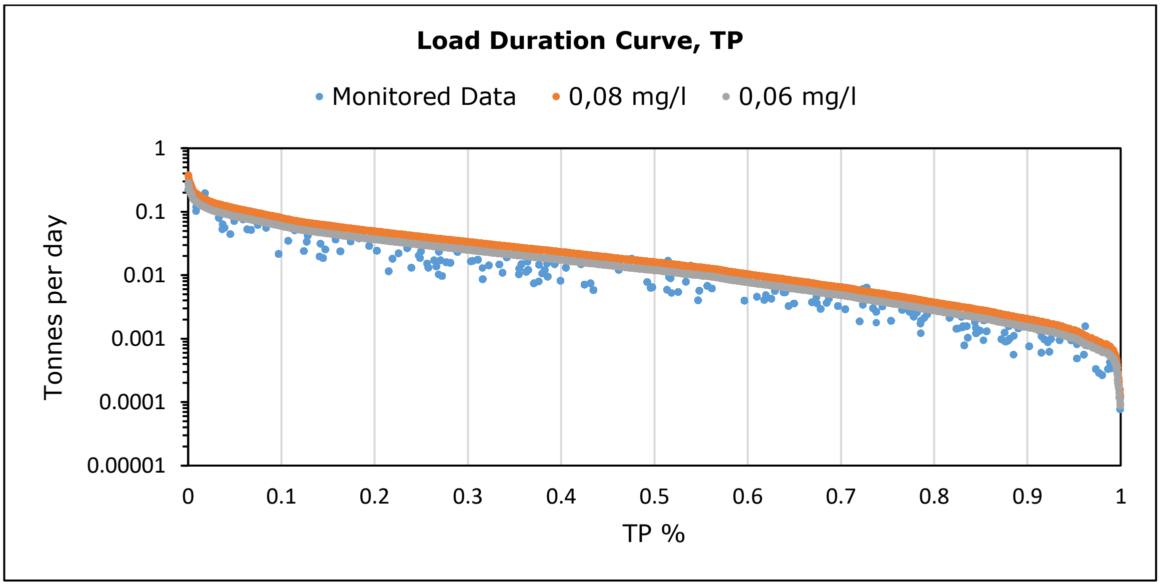


Figure 5.9: LDC for TP, Vihterpalu River

5.3 Keila River

The length of the watercourse of the river is of 116 km, and with its additional branches that number extends to 127,3 km [42]. The average flow of the river is of 6,45 m³/s.

There is a 6 m high natural waterfall that is located 1,7 km from the BS and at the waterfall, there is a hydropower station where on some occasions may disturb the hydrological regime of the river.

The lowest 1,8 km section of the river belongs to the Natura 2000 network [44].

The total catchment area, and the catchment area at the monitoring station, are of 669.3 km². The Keila River catchment area consists mostly of farmland and forest, which constitute 47 % and 45 % of its area [40].

Monitored data

The complete data of the daily flow from 1993 – 2019 was available for the Keila River.

The gathered data from the monitored load inputs for this study period for N and P were the following: In terms of N, the minimum was 0,59 mg/l, a maximum of 6,84 mg/l, and a mean value of 3,3 mg/l. For P, the minimum value was 0,023 mg/l, the maximum value was 0,27 mg/l, and a mean value of 0,07 mg/l. These values can be seen in Figure 5.10.

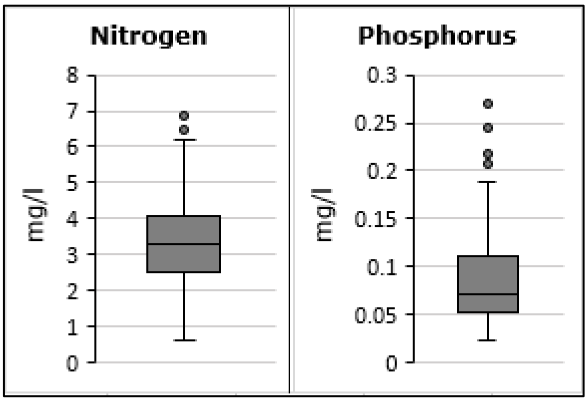


Figure 5.10: Mean content of N and P for Keila River

Changes in the mean values can be seen (in Table 4.3 and Table 4.4) when comparing these monitored values with the gathered data from the study period of 2009 – 2019. For this study period, the mean for N was 3,2 mg/l and 0,08 mg/l for P [40]. Although the changes do not make a significant impact, it shows a reduction for N and an increment for P.

The trend for N is evident when comparing these monitored data with the data gathered from the year 2018, here, the value for N was 3,0 mg/l. The value for P is the same as the long-term mean, 0,07 mg/l [43].

In the long-term daily flow monthly average in Figure 5.10 it is seen that the highest flows occur during April.

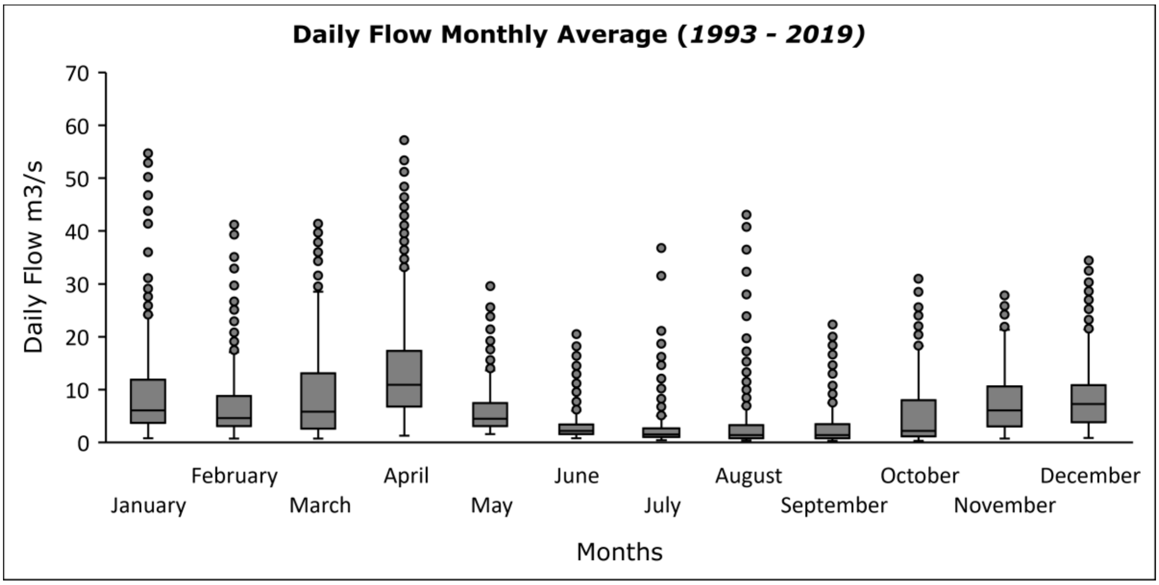


Figure 5.11: Daily flow monthly average, Keila River

The LDC for TN and TP show that there are continuous inputs throughout all the seasonal variations, meaning that there are point sources draining into the river. One of the main factors influencing the eutrophication in the area is the agricultural land use in the catchment area, and although it may have a significant impact in the nutrient inputs in the river, the point source may be the one which needs more attention. The number of households and industries connected to the sewage system of the municipality has grown in the recent years, increasing the amount of nutrients landing in the MWWTPs. This can be leading reason of the level of TP content in the river.

The mean value of point sources for the period of 2015 – 2019 are the following: 19,9 mg/l for TN and 1,3 mg/l for TP [40].

By analyzing the LDCs, it is clear that the TN have to make an important improvement in order to reach the established targets as most of the monitored data is shown above the limit line of 1,5 mg/l which is the lowest established limit, meaning that the river in terms of TN is in bad status.

In terms of TP, the monitored data varies through the whole year. It has a long-term mean value of 0,07 mg/l where the values divide almost half being above that value and the other half below it. From Figure 5.13, it is possible to see that if the established limit would be 0,06 mg/l (the lowest of the two established limits) the TP graph would have most of the monitored data above the line.

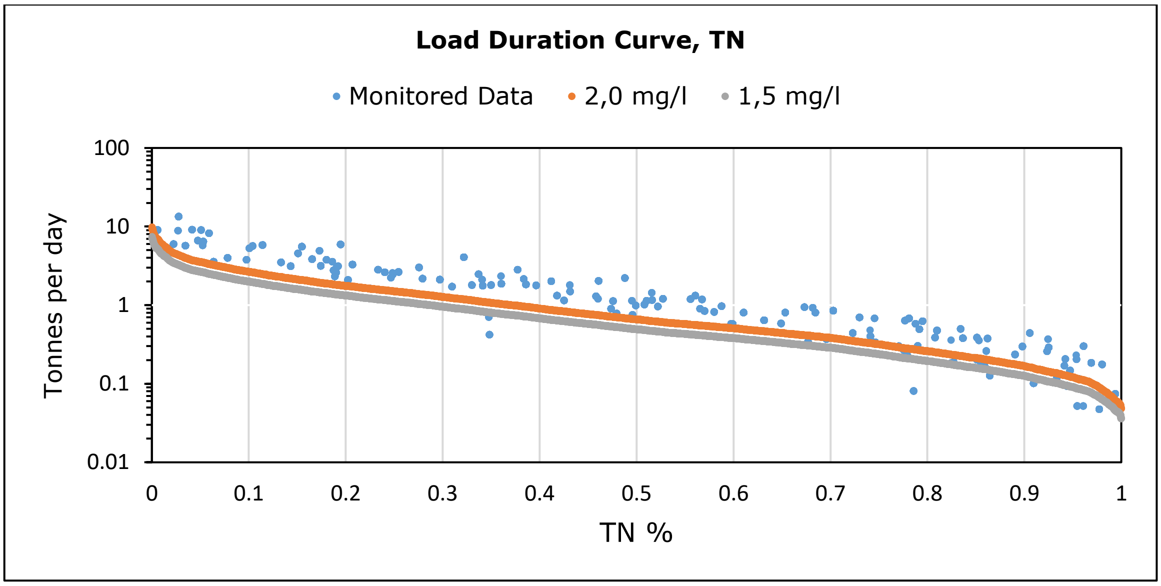


Figure 5.12: LDC for TN, Keila River

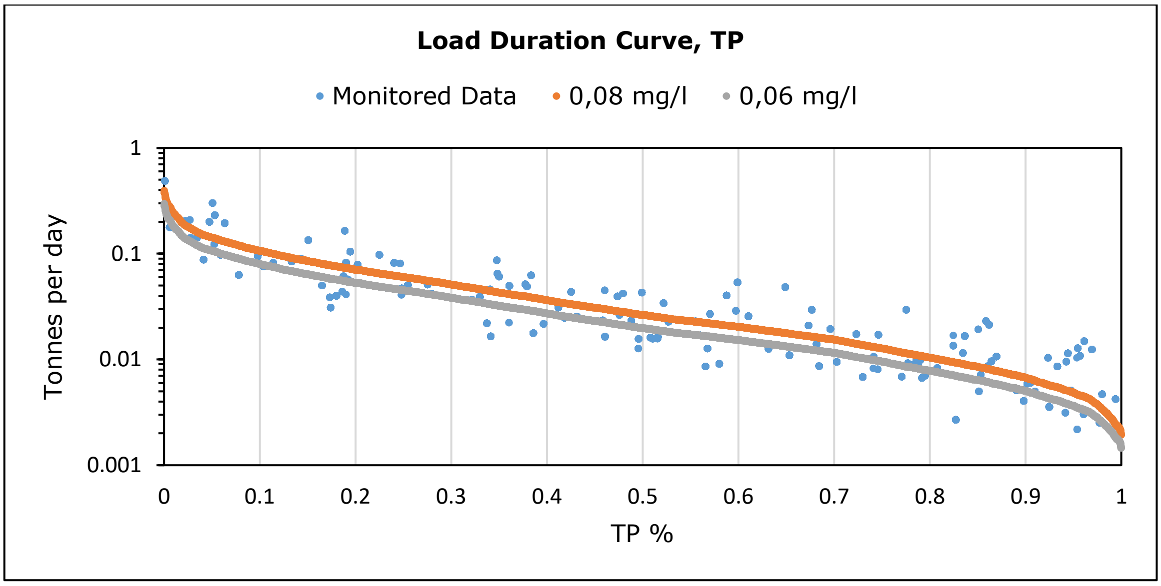


Figure 5.13: LDC for TP, Keila River

5.4 Vääna River

The Vääna River has two tributaries river Pääsküla and Vanamõisa stream. Before, the river had a length of 75 km a catchment area of 407 km², but in 1967, the upper part was directed to the Pirita River (the Angerja tributary) as part of the Tallinn's Drinking Water system [44].

The river has a length of 64 km and it is 69,5 km when adding its additional branches [42]. The average flow of the river is 1,19 m³/s.

The lowest 22 km section of the river belongs to the Natura 2000 network [44].

The total catchment area, and the catchment area at the monitoring stations, are of 315 km². From the catchment area 45 % is covered by agricultural land, 41,5 % by forests, 2,9 % of wetlands and 10,2 % of artificial influences [40].

Monitored data

Daily Flow information of the Vääna River was gathered from the available data from 1993 – 2011.

The gathered information from the nutrient loads from that period was the following: For N, there was a minimum value of 0,49 mg/l, a maximum of 13,6 mg/l, and a mean of 3,8 mg/l. In terms of P, the minimum was of 0,047 mg/l, the maximum of 0,33 mg/l and a mean value of 0,1 mg/l. These values can be seen in Figure 5.14.

The mean values for both N and P exceed the highest established limit of 2,0 mg/l and 0,08 mg/l.

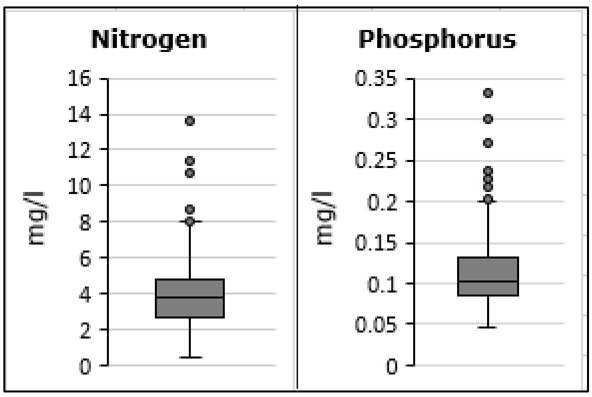


Figure 5.14: Mean content of N and P for Vääna River

From Tables 4.3 and 4.4, for the period of 2009 – 2019, it is possible to see that the mean value deceased for N as it shows a mean value of 2,9 mg/l and for P it has maintained without any significant change as the mean value is 0,11 mg/l [40]. Even with this significant drop in the mean value for N, the mean input value is still in clear exceedance with the target of 2,0 mg/l.

The mean values also have a change when comparing them to the monitored data from 2018. This data shows that N has an input of 2,3 mg/l which can be considered a good improvement when considering the long-term mean value of 3,8 mg/l [43]. For P, the gathered data is in bad status as it shows a value of 1,3 mg/l.

The long-term daily flow monthly average, Figure 5.15, shows that the Vääna River has had its highest flows during the month of April.

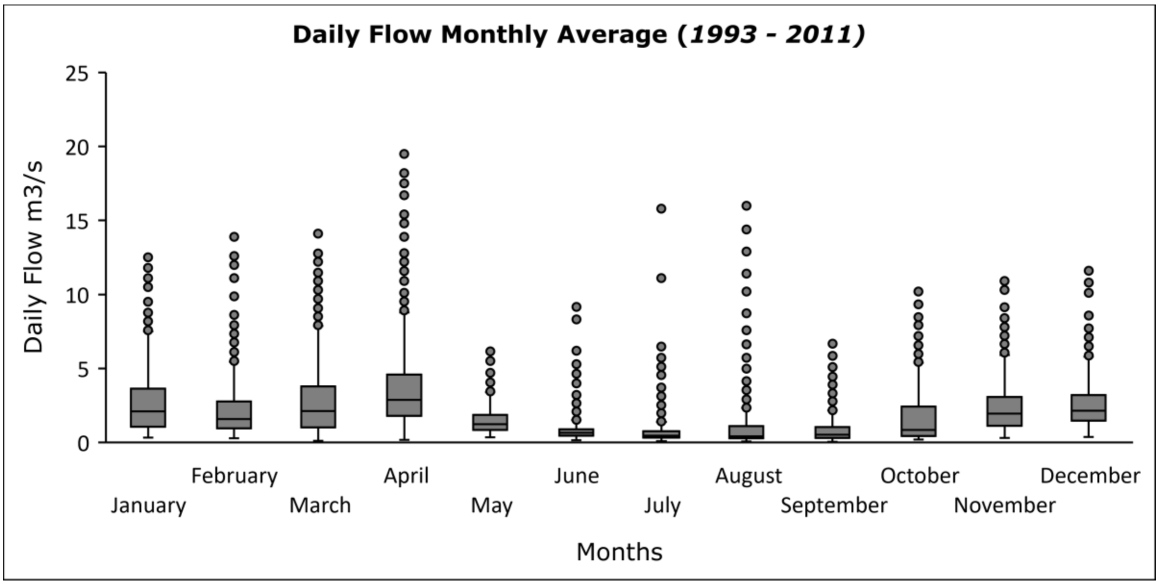


Figure 5.15: Daily flow monthly average, Vääna River

The bad quality water in the catchment area can be due to the intensive agriculture in the area.

Form the LDC of TN, it is appreciated that the exceedance inputs are throughout all the seasonal variations, meaning that besides the inputs entering the river through intensive agricultural practices, point sources should be also considered as an important factor. It is important to mention that during low flows, there were some monitored data that were below the lowest established limit of 1,5 mg/l, but in during high flows, all data exceeds both limit targets.

For TP, in Figure 5.17, it shows an exceedance through all the different seasonal variations and there is not much change between high flows and low flows. As seen in the LDC, almost all monitored values are above the exceedance of the highest established limit of 0,08 mg/l. Adding to the agricultural practice, point sources must also be reviewed.

As mentioned for both TN and TP, the agricultural sector has an important impact in the water quality of the Vääna River but point sources must also be reviewed. From the mean point source load inputs in the river during the period of 2015 – 2019, the values were the following: 3,8 mg/l for TN and 0,2 mg/l for TP [40]. These values show a significant exceedance from the highest established limits.

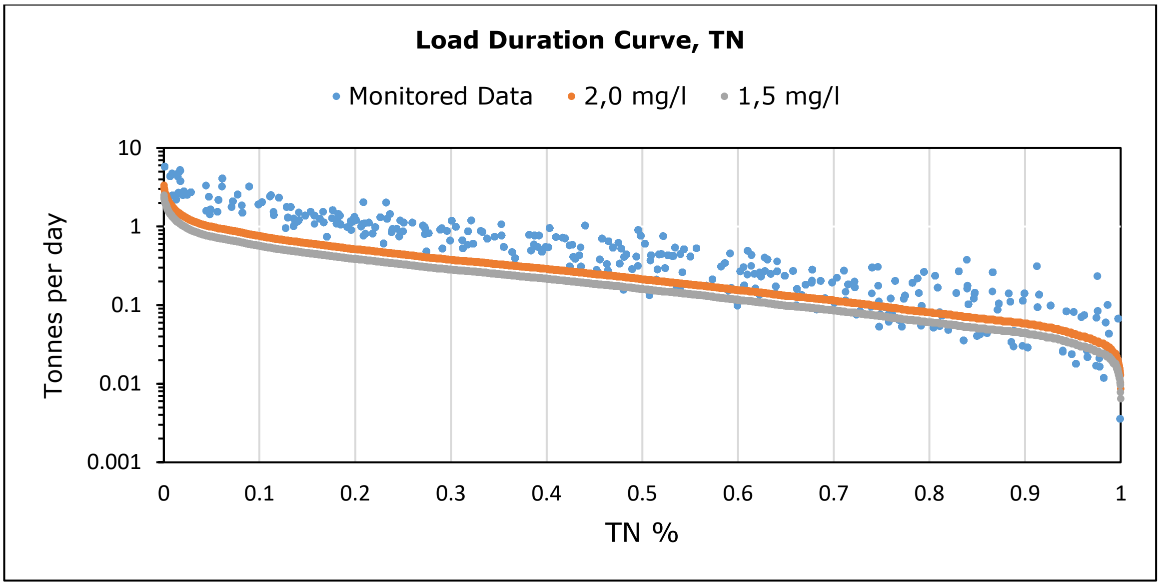


Figure 5.16: LDC for TN, Väana River

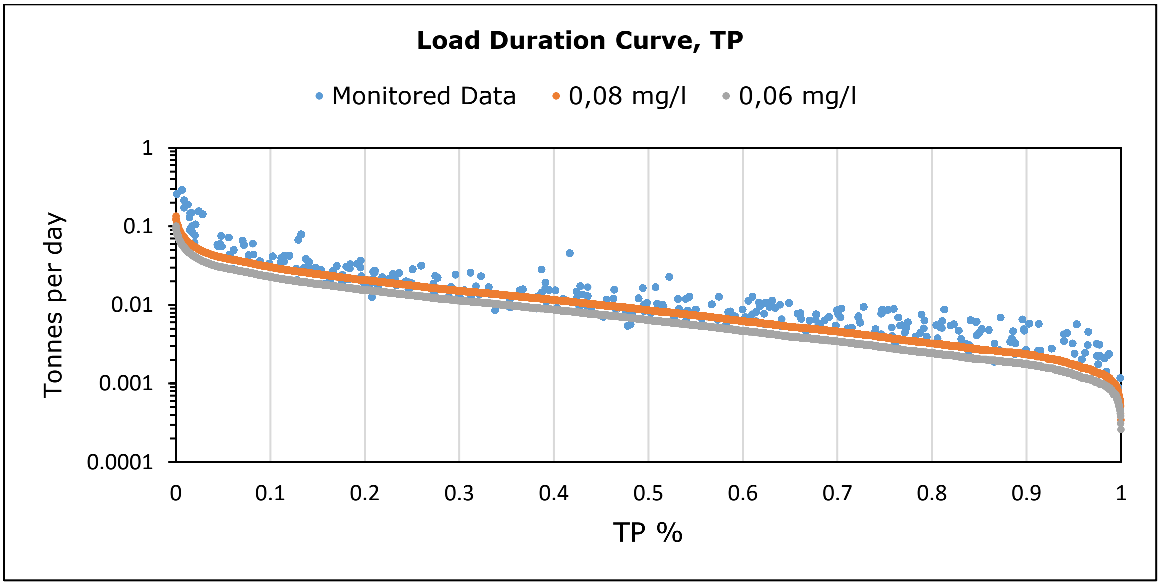


Figure 5.17: LDC for TP, Väana River

5.5 Pirita River

The Pirita River is an important section of Tallinn’s drinking water supply system. It has two major tributaries which are the rivers: Kuivajõgi, Tuhala, Angerja, and Leiva.

The length of the main river is 105 km, and by adding its additional branches it becomes 118,1 km of length [42]. The average flow of the river is 7,77 m³/s.

The lower 22 km of the Pirita river belongs to the Natura 2000 network [44].

The total catchment area is of 807,8 km² and the catchment area of the monitoring station is of 749 km². More than half of the area is covered by forest, 56 %, with second being the agricultural land with 37 % [40].

Monitored data

For Pirita River, the data was gathered from the following available data: 1993 – 1993 and 2007 – 2019.

The gathered data for the nutrient inputs in the river was the following: For N, the minimum input value was 0,36 mg/l, the maximum of 8,09 mg/l, and the mean value of 3,04 mg/l. For P, the minimum input was of 0,005 mg/l, the maximum of 0,13 mg/l and a mean input value of 0,05 mg/l. These values can be seen in Figure 5.18.

The mean value for N is above the highest exceedance limit of 2,0 mg/l, meaning that it is in a very bad status. In terms of P, the mean is below the lowest established target of 0,06 mg/l, therefore P is considered to be in a good status.

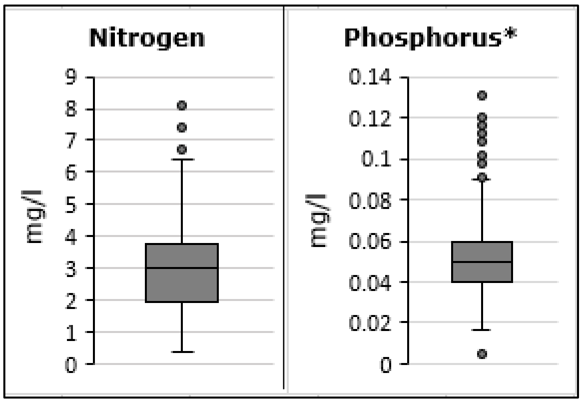


Figure 5.18: Mean content of N and P for Pirita River

These long-term mean values can be compared to a more recent mean in order to understand if there has been an improvement or deterioration of the quality in recent years in comparison to the long-term.

For Pirita River, the mean values for the period of 2009 – 2019 have maintained stable. For N, the mean value is 2,9 mg/l and in comparison, with the long-term mean of 3,0 mg/l there is no significant difference [40]. In terms of P, the mean value has maintained the same, 0,05 mg/l and therefore it is still in compliance with the targets.

For a more specific data, these long terms values can be compared to the data gathered in 2018. These values show a reduction for both N and P. For N, the monitored data in

2018 was of 2,5 mg/l which is closer to the target but still in exceedance, and for P, it shows a reduction as the monitored value was of 0,04 mg/l [43].

In Figure 5.19, the daily flow monthly average of the Pirita River shows that the highest flows occur during the month of April.

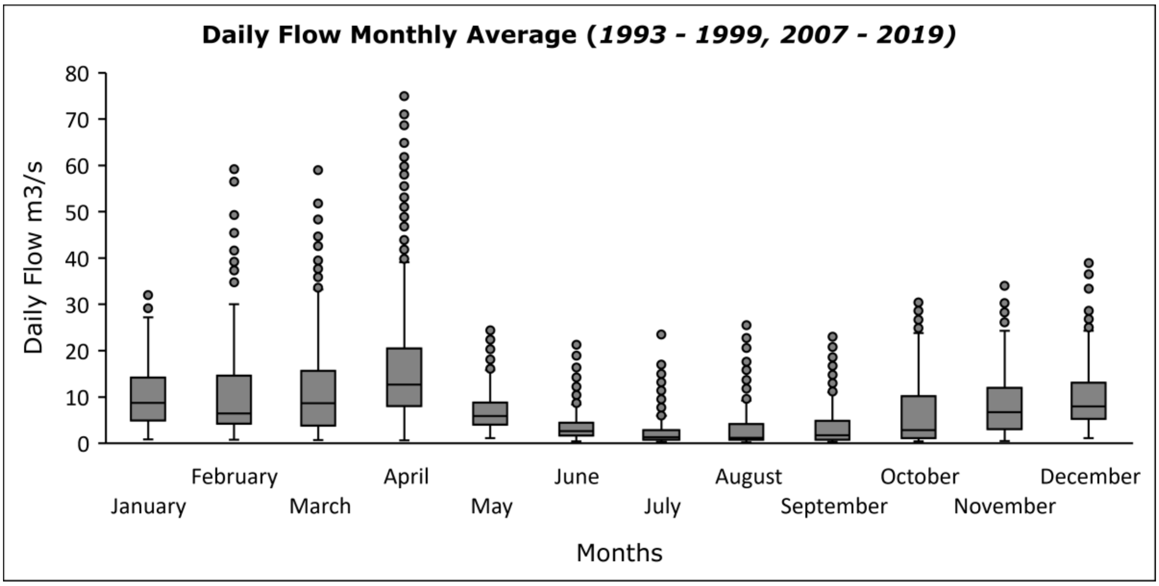


Figure 5.19: Daily flow monthly average, Pirita River

In Figure 5.20, is it shown that the load inputs are spread throughout all the seasonal variations. Adding to the agricultural impact in the river, the point sources can be an important factor in the area. The reason is that during the dry conditions, all the monitored data is exceeding the established limit, and in these cases, it can be attributed to point sources inputs.

For TP, almost all the monitored data is under the established limits seen in Figure 5.21. Although it is possible to see that if we consider the lowest target as the limit, 0,06 mg/l, there are monitored data throughout all the seasonal variations that are in exceedance. This can also be attributed from the inputs from the point sources.

The mean values of point sources from the period of 2015 – 2019 are high and above the established limits for both TN and TP. The mean values are 8,5 mg/l for TN and 0,04 mg/l for TP [40]. These values make it clear that the point sources are to be attributed for the contamination of the waters of Pirita River and that there must be a reduction from both nutrients as these mean values are far from the established targets of 2,0 mg/l (for TN) and 0,08 mg/l (for TP).

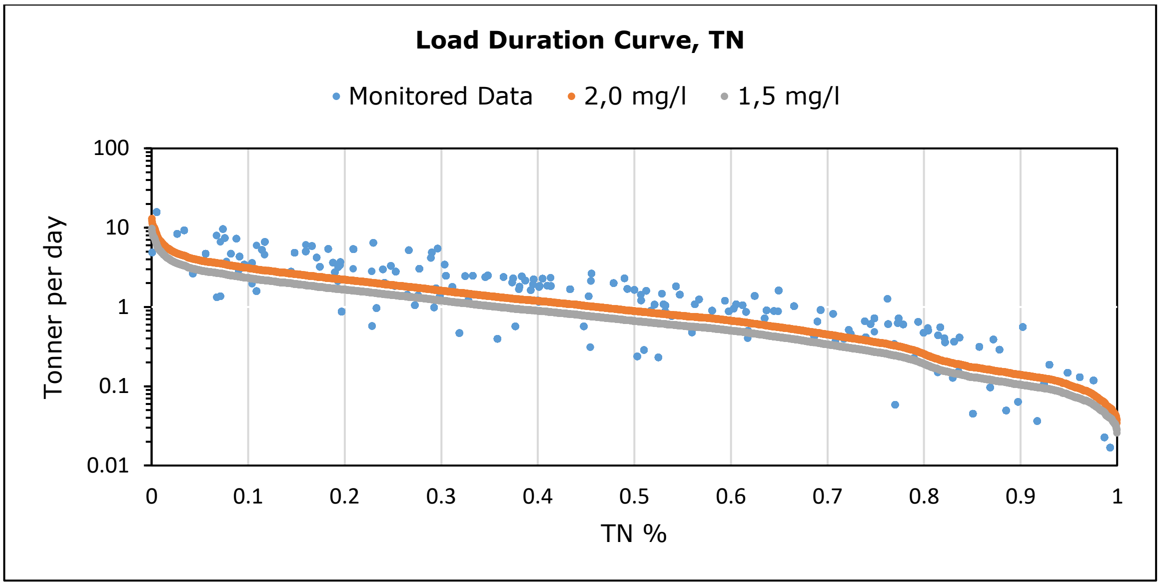


Figure 5.20: LDC for TN, Pirita River

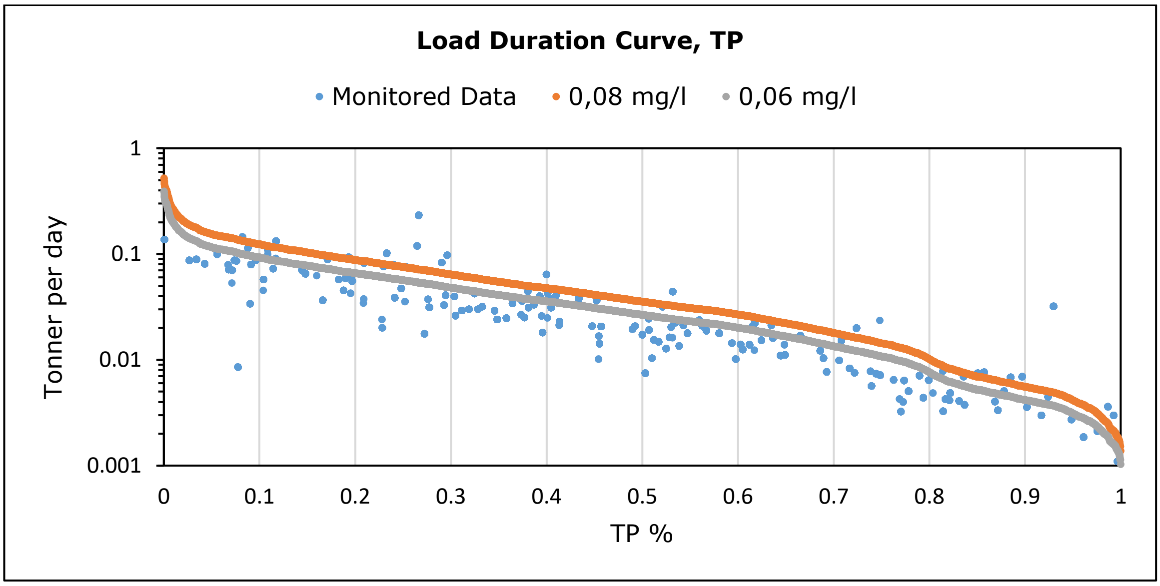


Figure 5.21: LDC for TP, Pirita River

5.6 Jägala River

The river runs mostly in the north-western part of the country, passing through Järva and Harju counties and drains into Ihasalu Bays. The Jägala River has six major tributaries, these rivers are: Ambla, Jänijõgi, Mustjõgi, Aavoja, Soodla and Jõelähtme.

The river belongs to the Natura 2000 network from the river’s mouth to the 7 m waterfall that is located 4,3 km from the coast [44].

As Pirita River, Jägala River is also part of Tallinn’s drinking supply system and because of this, extra water is directed from Pärnu River to it.

The length of the river is 97 km, and by adding its external branches the length extends to 119 km [42]. The average flow of the river is 7,3 m³/s.

Through the course of the main river there are several dams, being Linnamae hydroelectric power plant the highest with 11 m of height which is located 1,3 km from the river’s mouth [45].

The total catchment area of the river is 1481,1 km² including the catchment area of the monitoring stations. The land is mostly covered by forest, with 62,5 %; agricultural land covers 31 % of the area and wetland covers 4,4 % [40].

Monitored data

All data was available during the period of 1993 – 2019 form the Jägala River.

The information gathered with respect to the nutrient inputs during that period is the following: For N, the minimum value was 0,65 mg/l, the maximum value was 5,43 mg/l, and a mean value of 2,5 mg/l. In terms of P, the minimum value was 0,02 mg/l, the maximum value of 0,7 mg/l, and had a mean value of 0,04 mg/l. These values are represented in Figure 5.22, the asterisk symbol besides Phosphorus means that the highest value (0,7 mg/l) was excluded from the box and whiskers plot for a better representation of the recorded data.

The mean value of N exceeds the highest of the established limits, 2,0 mg/l. P on the other hand, presents values that are under compliance even when considering the lowest of the established limits (0,06 mg/l).

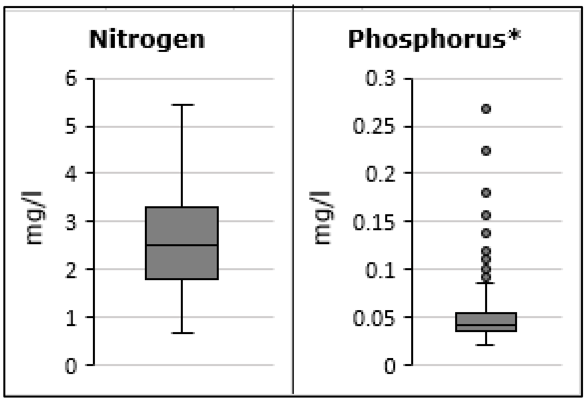


Figure 5.22: Mean content of N and P for Jägala River

When comparing these gathered data with the mean values for the recent period of 2009 – 2019 in Tables 4.3 and 4.4, it is seen that the inputs have not changed. The values presented during that period were 2,5 mg/l and 0,05 mg/l for TN and TP [40], respectively. These values demonstrate that the in terms of TN the mean has stayed the same with the long-term period, and in the case of TP the value has increased from 0,04 mg/l to 0,05 mg/l, but even when considering this increase, P is still under compliance with the lowest established target.

The long-term daily flow monthly average for the Jägala River shows that the highest flows occur during the month of April.

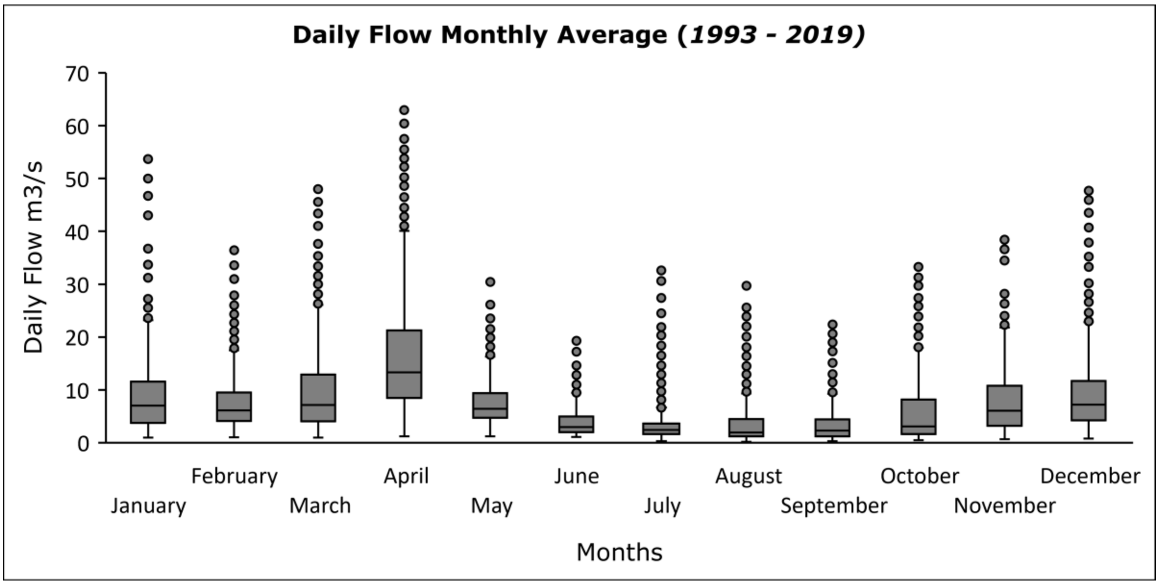


Figure 5.23: Daily flow monthly average, Jägala River

In Figure 5.24, from the LDC for TN the inputs are spread throughout the seasonal variations, but it shows low inputs during the low flows in comparison to the other sections. This can mean that even when considering that 31 % of the total catchment area is of agricultural land, the focus should be put in the point sources. When considering the lowest limit of 1,5 mg/l most of the monitored data will be in exceedance and therefore the river can be in bad status in terms of TN.

For TP, Figure 5.25, the LDC show that most of the monitored data are below the target line. Although during low flows most of the monitored values are in exceedance with the highest of the established limits. Meaning that there must be a focus in point sources.

The point sources mean values for TN and TP during the period of 2015 – 2019 show that there is exceedance from both nutrients. For TN, the value is of 16,7 mg/l which is a high value. For TP, the value is of 1,82 mg/l which also exceeds the highest of the established targets [40].

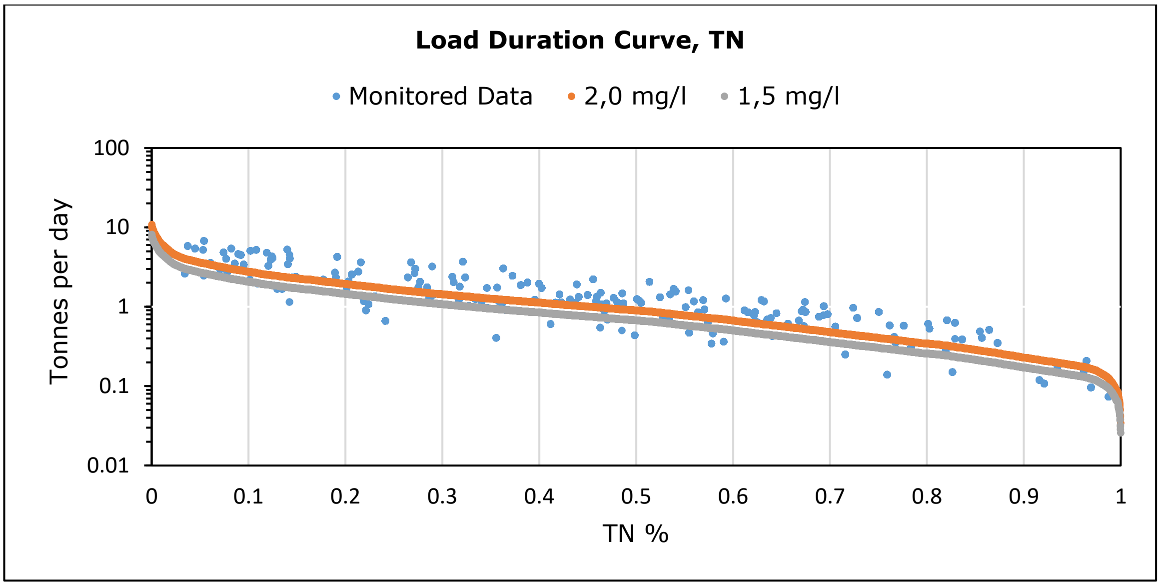


Figure 5.24: LDC for TN, Jägala River

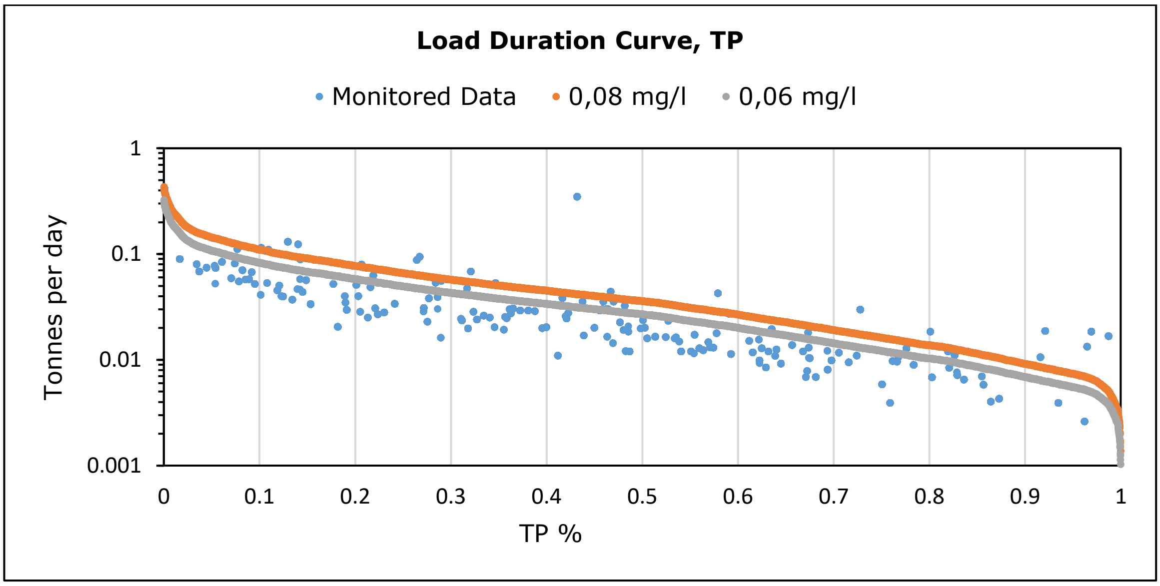


Figure 5.25: LDC for TP, Jägala River

5.7 Pudisoo River

The Pudisoo river is in Harju county, and it discharges into the Kolga Bay. Its main river has a length of 28 km, and when adding its additional branches, it extends to 31,8 km [42]. The river has an average flow of 1,04 m³/s.

The river has a total catchment area of 143,7 km², and the catchment area of the monitoring station is of 132 km². Most of the land is covered by forest with 75 %, agricultural land constitutes 20 % of the total land, wetland 3,4 % and artificial influences compose a 1,4 % [40].

Monitored data

The gathered data from the Pudisoo River was from the complete period of 1993 – 2019.

The gathered data of the nutrient loads for this period was the following: For N, the minimum input value was 0,17 mg/l, the maximum input value was of 2,84 mg/l, and the mean value was 1,3 mg/l. For P, the minimum value was of 0,04 mg/l, the maximum value was of 0,34 mg/l and the mean value was of 0,08 mg/l.

In both cases, for N and P, the mean values are in compliance with the highest established targets. In the case of N, it is in compliance with the limits even if considering the lowest of the limits (1,5 mg/l) as the target.

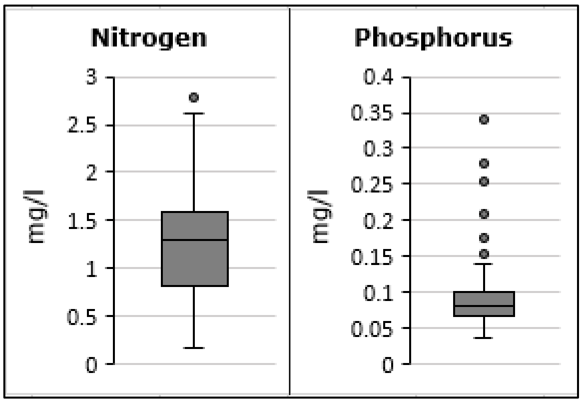


Figure 5.26: Mean content of N and P for Pudisoo River

When comparing the long-term mean values with the mean of the recent period of 2009 – 2019 in Tables 4.3 and 4.4 [40], in terms of TN, the value has maintained stable as it shown the same 1,3 mg/l mean value as the long-term value. For TP, the mean value shows the higher value of 0,09 mg/l which is higher than the highest established target of 0,08 mg/l and therefore the quality of the water can be in poor status in terms of TP.

In 2018 [43], the monitored data for TN was 0,93 mg/l which is a lower value than the means stated above, therefore the river can be consider having a good status for TN. In terms of P, the value obtained from the monitored data was 0,09 mg/l which is the same value of the mean from 2009 – 2019, therefore in this case, the river can be considered to be in bad status as it is not in compliance with the targets.

From Figure 5.27, the long-term daily flow monthly average shows that the rivers receive its highest flows during the month of April.

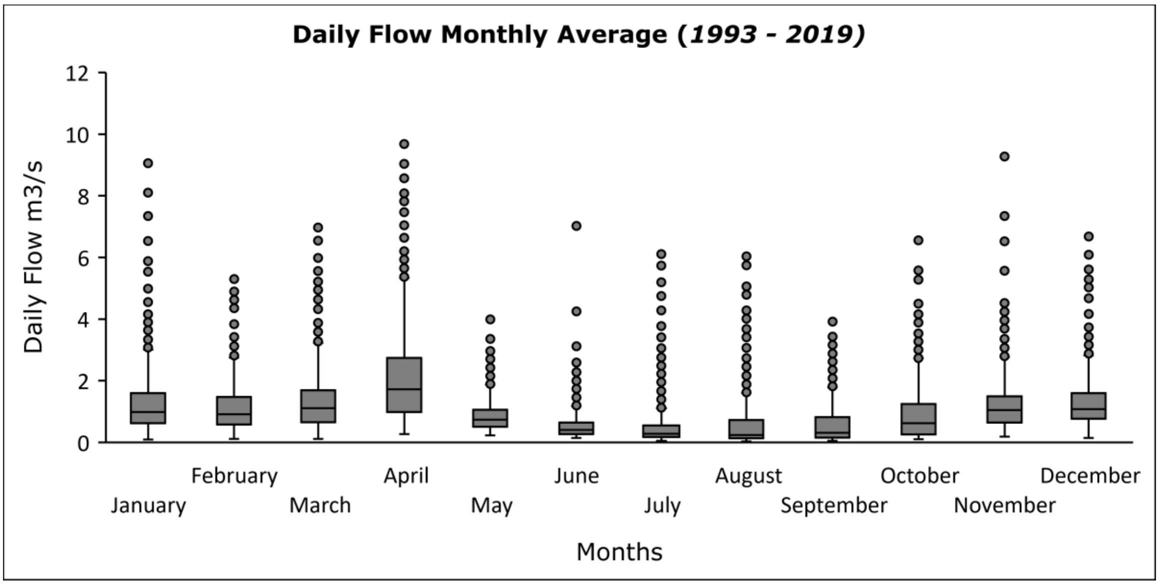


Figure 5.27: Daily flow monthly average, Pudisoo River

From the LDC of TN in Figure 5.28, most of the monitored data values are below the established limits even when considering 1,5 mg/l as the limit.

For TP, the case is different (Figure 5.29). About half of the data stands above the target line and therefore are not in compliance with the established targets. If we consider the lowest target as the limit value (0,06 mg/l) almost all the data would be above the limit line.

This excess of P can be associated to the agricultural practice in the area. The reason for this is that the mean values for TN and TP of the point sources during the period 2015 – 2019 are 0,29 mg/l and 0,01 mg/l, respectively [40]. These data demonstrate that there are no significant inputs from point sources for TN not TP.

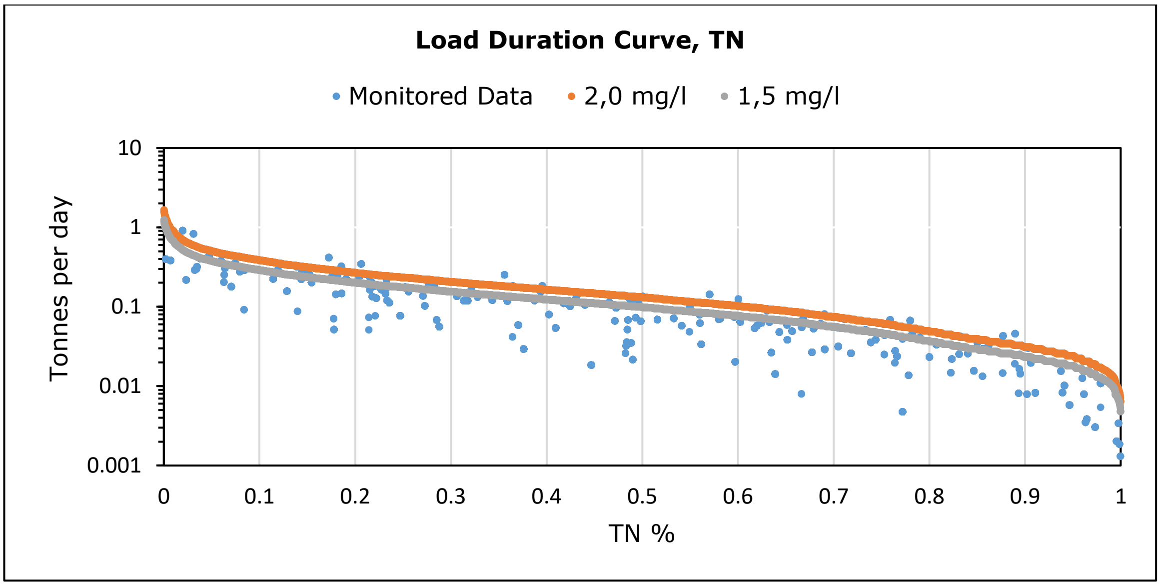


Figure 5.28: LDC for TN, Pudisoo River

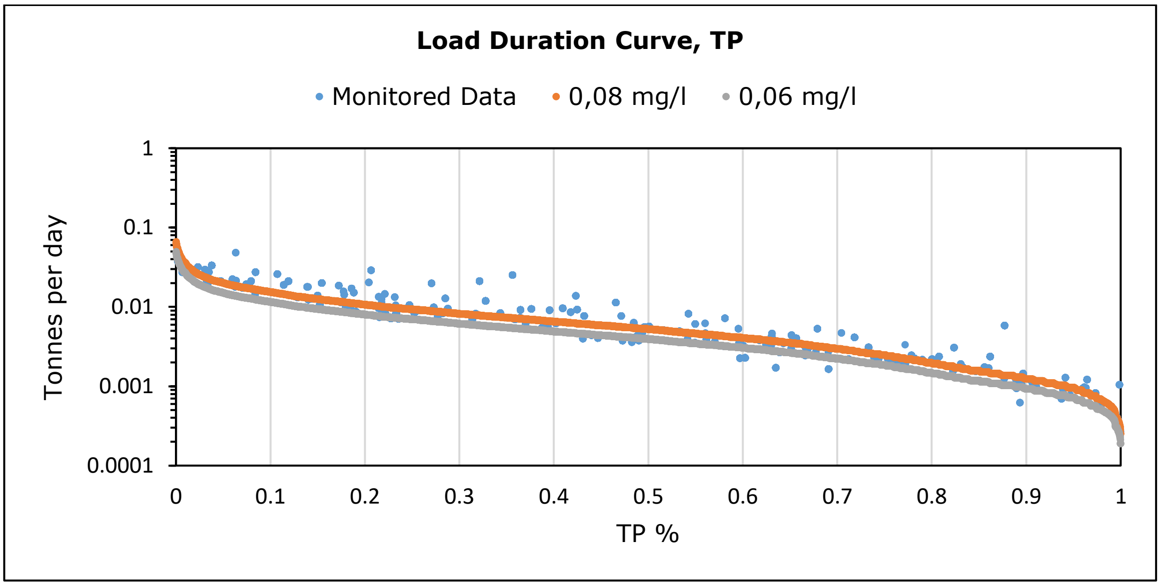


Figure 5.29: LDC for TP, Pudisoo River

5.8 Valgejõgi (River)

The Valgejõgi main river has a length of 85 km, and with its additional branches it extends to 105,4 km [42]. The average flow of the river is 3,49 m³/s.

Valgejõgi starts from a small spring fed by the Porkuni Lake, and it does not possess any significant tributaries. The river has a stable flow regime as spring water constitutes 58 % of the annual amount of flow.

Most of the river belongs to the Natura 2000 network [44].

The total catchment area is of 451,5 km², same as the catchment area of the monitoring station. The catchment area mostly consists of agricultural land and forests, representing 29 % and 62 %, respectively [40].

Monitored data

The complete data from the period of 1993 – 2019 was available for Valgejõgi.

The gathered information from the monitored data of the nutrient loads was the following: For N, the minimum value was of 0,32 mg/l, the maximum value was of 3,9 mg/l, and the mean value was 1,9 mg/l. In terms of P, the minimum value was of 0,01 mg/l, the maximum recorded data was of 0,21 mg/l and the mean value was of 0,04 mg/l. These values can be seen in Figure 4.30.

From these recorded data, the mean value for N is in exceedance with the lower established limit of 1,5 mg/l but in compliance with the highest limit of 2,0 mg/l. For P, even when considering the lowest data as the target, the mean value is under compliance as is it 0,02 mg/l lower than the established limit of 0,06 mg/l.

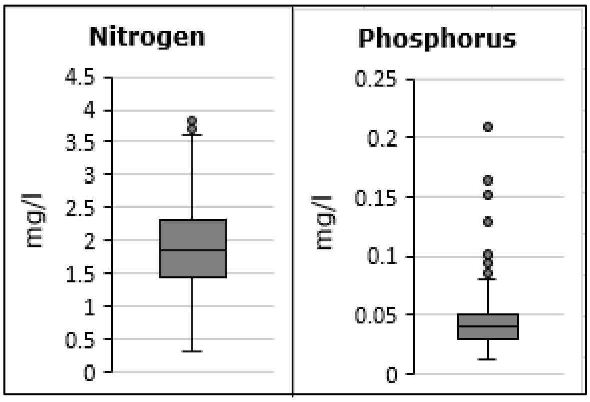


Figure 5.30: Mean content of N and P for Valgejõgi (River)

When comparing these long-term gathered data to the data of a more recent period in Tables 4.3 and 4.4 (2009 – 2019), it is seen that the inputs have maintained stable as the value for N during this period are: 2,0 mg/l for TN and 0,04 mg/l for TP [40]. For both cases, N and P, the conditions have maintained the same and they are both in compliance with the highest of their established target.

In 2018, the monitored data provided recorded data similar the means mentioned before. For TN the value was of 2,0 mg/l and 0,03 mg/l for TP [43]. In this case the value for TP has decreased.

In Figure 5.18, the long-term daily flow monthly average shows that the river receives its highest flows during the month of April.

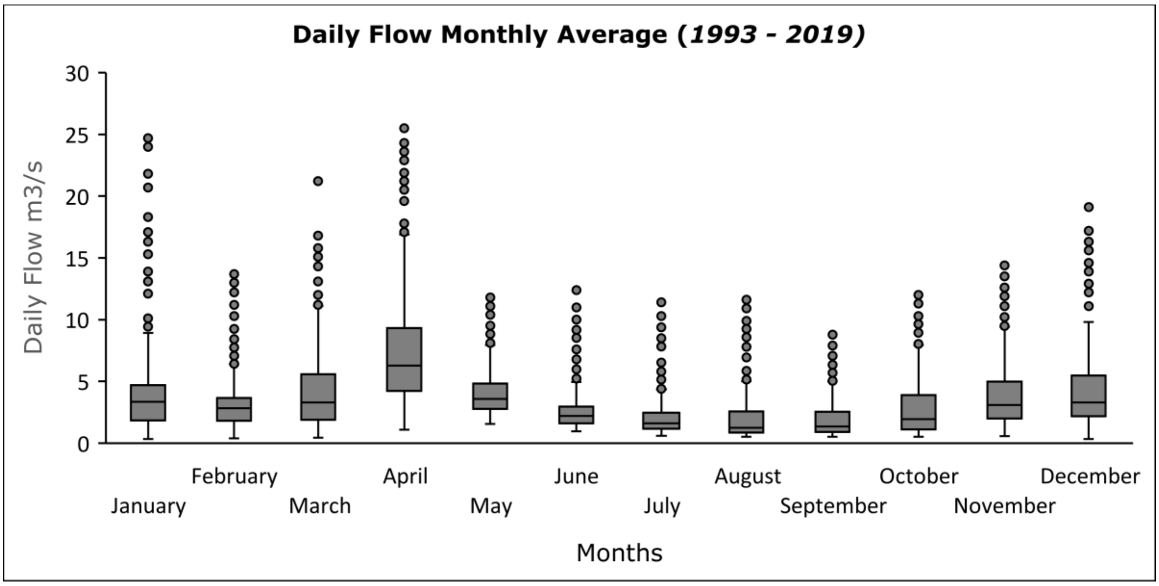


Figure 5.31: Daily flow monthly average, Valgejõgi (River)

From Figure 5.32, the values of the monitored data are shown throughout the seasonal variation, and in all cases, there are values that exceeds the limits. During the low flow periods, most of the monitored values are below the established limit even when considering the highest value of 2,0 mg/l. Therefore, agriculture could have a significant impact in TN.

For TP, in Figure 5.53, it is shown that most of the monitored data has been below the established target, even when considering the lowest target of 0,06 mg/l.

The mean value from the point sources gathered during the period of 2015 – 2019 are the following: 2,8 mg/l for TN and 0,17 mg/l for TP [40]. For both cases, the values are in exceedance of the established targets. The high values for TN can be the cause of the exceedance in the recorded data.

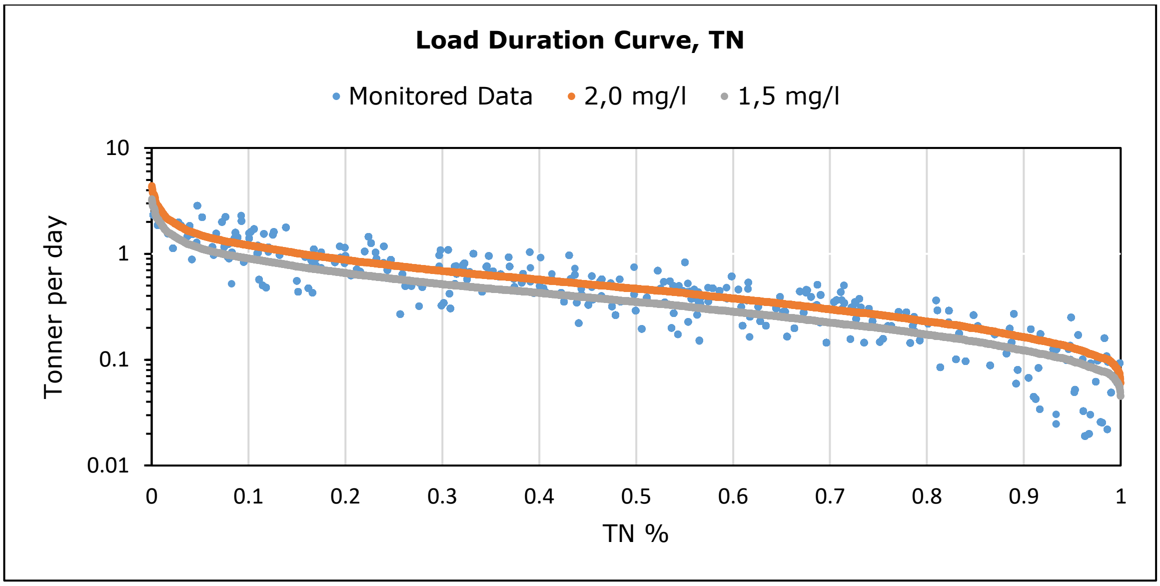


Figure 5.32: LDC for TN, Valgejõgi (River)

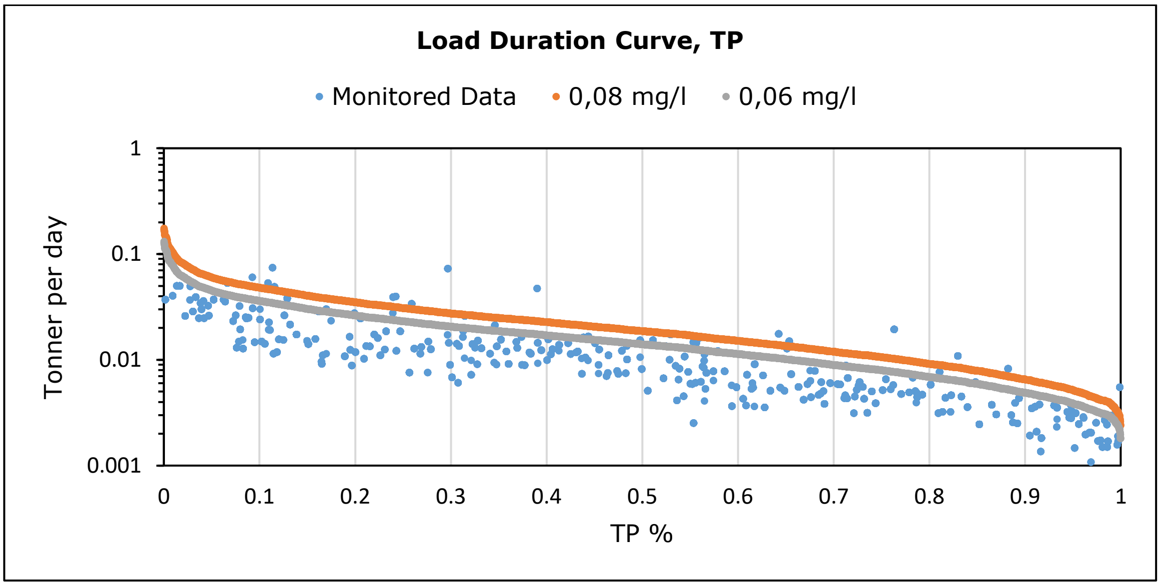


Figure 5.33: LDC for TP, Valgejõgi (River)

5.9 Loobu River

Loobu river, located in Jõepere village in Pandivere, and has three major tributaries which connect to the middle and upper section, these rivers are: Udriku, Vohnja and Läsna. The river drains to the Eru Bay.

The river has three manmade constructions. The lowermost is located at 10.4 km from the coast and it has an operational power station that regularly disturbs the natural flow regime. There are also some small waterfalls that have a combined height of about 4 m.

The main river has 62 km of length and it extends to 66,5 km when adding its additional branches [42]. The river has an average flow of 2,36 m³/s.

Most of the river belongs to the Natura 2000 network [44].

The river has a total catchment area of 314 km², and the catchment area of the monitoring station is of 308 km². The catchment area mainly consists of forest and agricultural land as they cover 51,6 % and 45 %, respectively [40].

Monitored data

For Loobu River, the study was made from the available data form the period of 2007 – 2019.

The gathered information of the nutrient inputs during this period resulted in the following: For N, the minimum value was of 0,59 mg/l, the maximum recorded value was of 7,8 mg/l, and it had mean value of 3,7 mg/l. In terms of P, the minimum value was of 0,02, the maximum value was of 0,15 mg/l, and the mean was 0,04 mg/l. These monitored values are represented in figure 5.34.

Form these recorded data it is seen that for N the mean value exceeds by 1,7 mg/l the highest of the established data (2,0 mg/l), and for P, the mean value is in compliance even when considering the lowest of the established limits (0,06 mg/l).

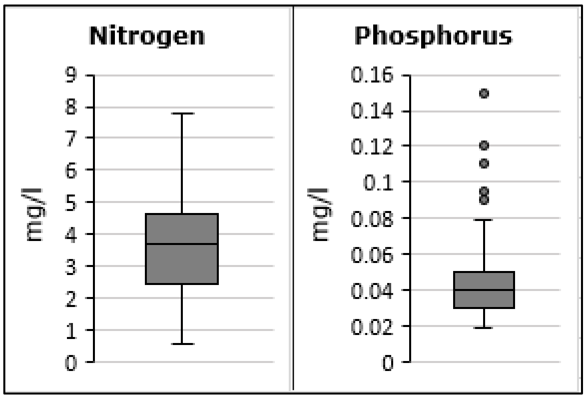


Figure 5.34: Mean content of N and P for Loobu River

These long-term values can be compared to the mean values from a more recent study period, 2009 – 2019. The values recorded during this period resulted in mean values of 3,4 mg/l and 0,04 mg/l for N and P, respectively [40]. Meaning that for N, the value has decreased, but still shows a result that is above the limit of 2,0 mg/l established for N. There has been no change for P as the mean is still 0,04 mg/l, same as the long-term mean.

There is a change in the value when considering the value obtained from the monitored data during the year 2018. During this time, the value obtain was 2,7 mg/l for TN and 0,034 mg/l for P [43]. In terms of TP, the value stayed stable in 0,04 mg/l but in terms of TN, there is a significant decrease to 2,7 mg/l.

In Figure 5.35, the long-term daily flow monthly average shows that during April is when the river receives its highest flows.

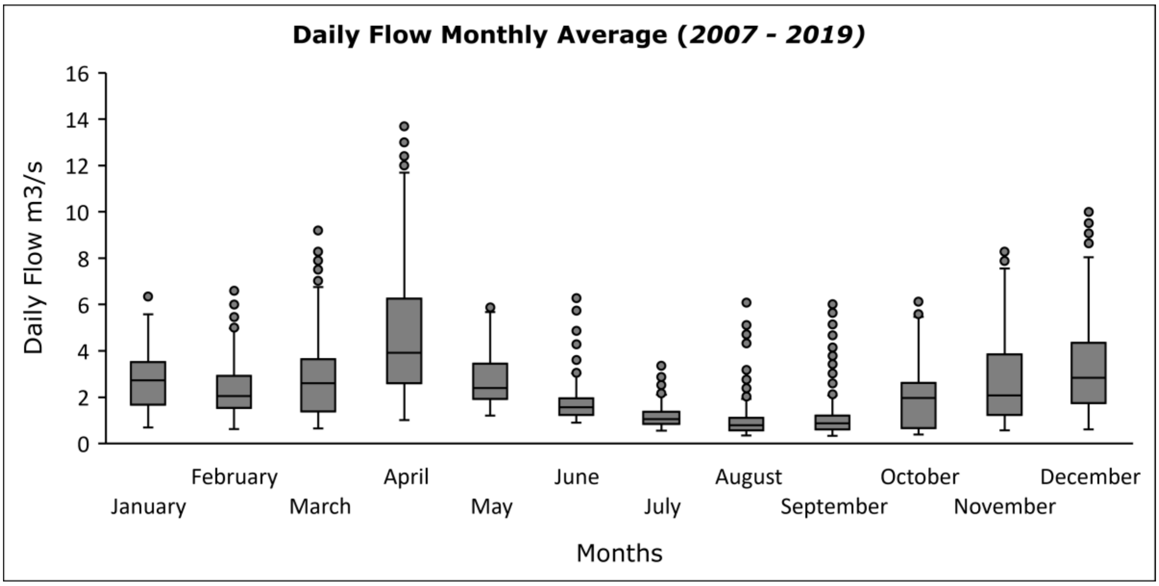


Figure 5.35: Daily flow monthly average, Loobu River

For TN, Figure 5.36, a major part of the monitored data is standing above the limit line of 2,0 mg/l. It is important to notice that whether point sources may have an impact on the water quality of Loobu River, agriculture may be the leading cause of the contamination as there are no data above the target line during low flows.

The case is different for TP, in Figure 5.37, it is seen that most of the recorded data appears to be in compliance with the targets as most of the data is under the target line.

The mean values for the recorded data of point sources during the period of 2015 – 2019 gave the following results: 2,2 mg/l for TN and 0,1 mg/l for TP [40]. Both values are above the established limits. Although the 2,2 mg/l for N is above the 2,0 mg/l target, it is lower than the 3,4 mg/l mean for TN. Therefore, the source of pollution can be focused on agriculture as it covers a significant 45 % of the total catchment area.

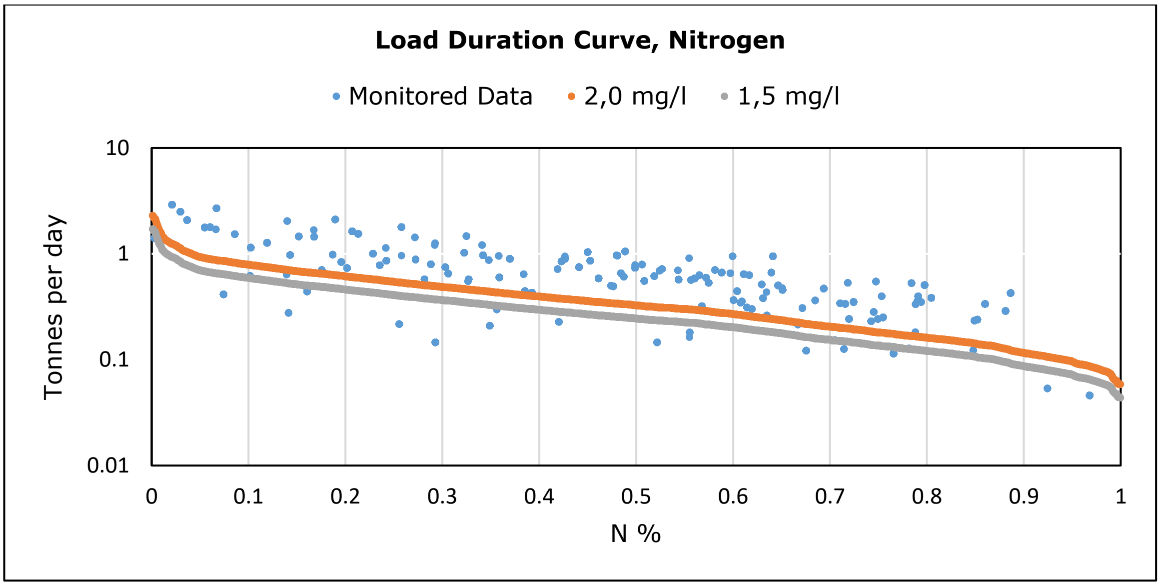


Figure 5.36: LDC for TN, Loobu River

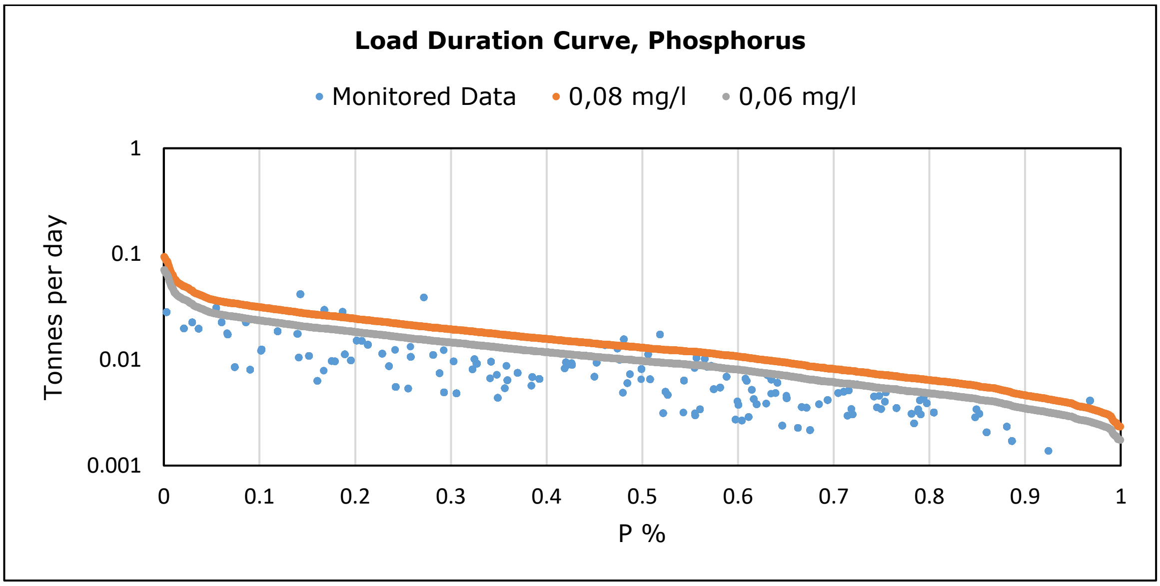


Figure 5.37: LDC for TP, Loobu River

5.10 Selja River

The river has just one major tributary which is the Sõmeru River which enters from the upper reach of the river and is nourished by springs (Môdriku, Râgavere and Vetiku), and there is a dam located at 39,2 km from the sea.

Most of the lower part of the river belongs to the Natura 2000 network [44].

The main river is 44 km long and when adding its additional branches that number extends to 47,7 km [42]. The river has an average flow of 3,19 m³/s.

The river has a total catchment area of 322,6 km², and the catchment area of the monitoring station is of 310 km². The catchment area mainly consists of agricultural land as it is 67 % of the total area, being followed by forest with 28,7 % and artificial influences with 4,4 [40].

The southern part of the basin is in the Pandivere Upland which is known to have the most fertile soil in Estonia and therefore it is a highly cultivated area.

Monitored data

The data for Keila River was gathered from the years 2011 – 2019.

The recorded data from the nutrient inputs during that period provided the following: For N, the minimum value was of 2,2 mg/l, the maximum value was of 13,0 mg/l, and the mean was of 5,7 mg/l. In terms of P, the minimum value was of 0,01 mg/l, the maximum value was of 0,46 mg/l, and the mean was 0,06 mg/l. These values are provided in Figure 5.38.

From these recorded inputs there is a significant amount of pollution in the Selja River in terms of the inputs of N. Even when using the minimum value, it is seen that it exceeds the highest established target of 2,0 mg/l and it almost triples that value. For P, the mean value stands in compliance with the lowest of the established targets.

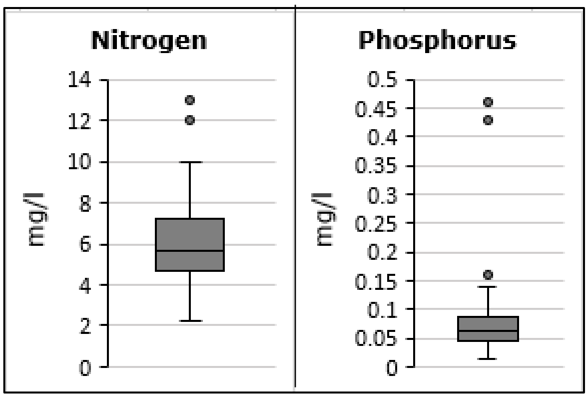


Figure 5.38: Mean content of N and P for Selja River

The data from a more specific period, 2009 – 2019, demonstrate that the river is not getting any improvement, and on the contrary, it provides data superior of those of the long-term mean. The mean during this period were: 5,8 mg/l for N and 0,07 mg/l for P [40]. The mean values have increased for N and P, and now when considering P, it exceeds the lowest of the established limits (0,06 mg/l), but it shows compliance with the highest target (0,08 mg/l).

These values can be compared of those of 2018 in order to see a trend. The recorded data during this year were: 5,9 mg/l for TN and 0,05 mg/l for TP [43]. These values show that the inputs of TN have an increasing trend, and for TP, the value has decreased to the below the established targets.

In Figure 5.39, it is shown that during the long-term period the highest flow occur during the month of April.

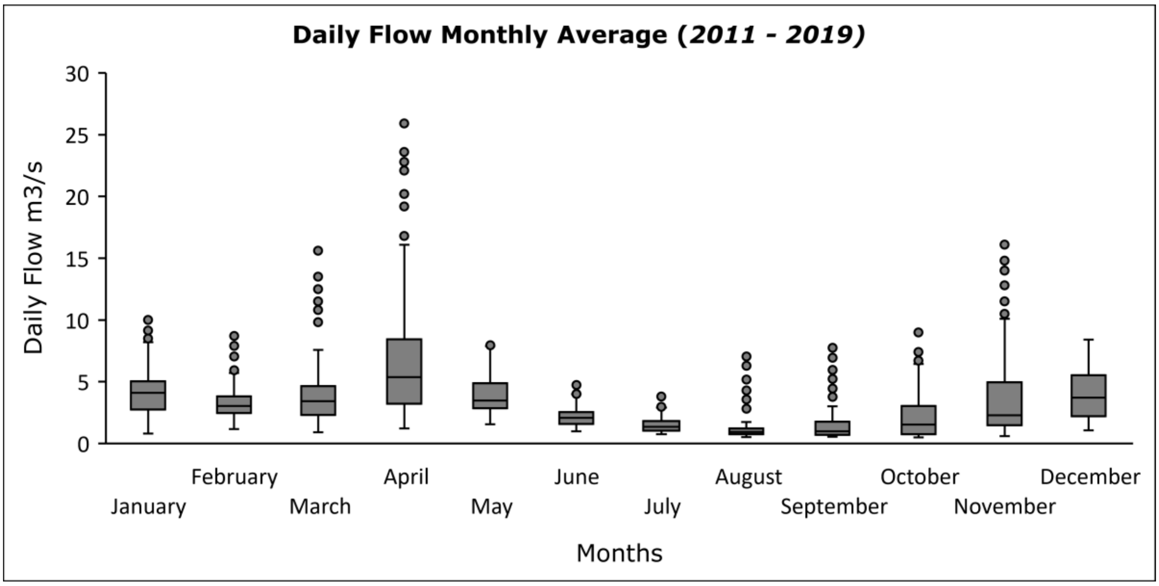


Figure 5.39: Daily flow monthly average, Selja River

The LDC for TN shown in Figure 5.40 can clearly demonstrate that all the monitored values during the 2011 – 2019 period were exceeding the highest established limit of 2,0 mg/l. This trend of exceedance can be seen throughout the year, meaning that even if the arable land in the area is significant and the agricultural sector is big, point sources must have the most significant impact as there are load inputs even at low flows.

The LDC for TP shows the same trend but with different percentage (Figure 5.41). Most of the input values are in compliance with the established limit of 0,06 mg/l, but it is evidently that point sources must have an impact in the in TP as there are inputs during low flows that exceed the highest of the established targets (0,08 mg/l).

The waste-water pollution (point sources) from Rakvere and its surroundings provide the highest concentration to the basin area. For Selja River the mean point source input load during the period of 2015 – 2019 was of 26,4 m/l for TN, which is significantly higher that the established limit. For TP the mean value is also high as it is 0,9 mg/l, which is also higher than its limit [40].

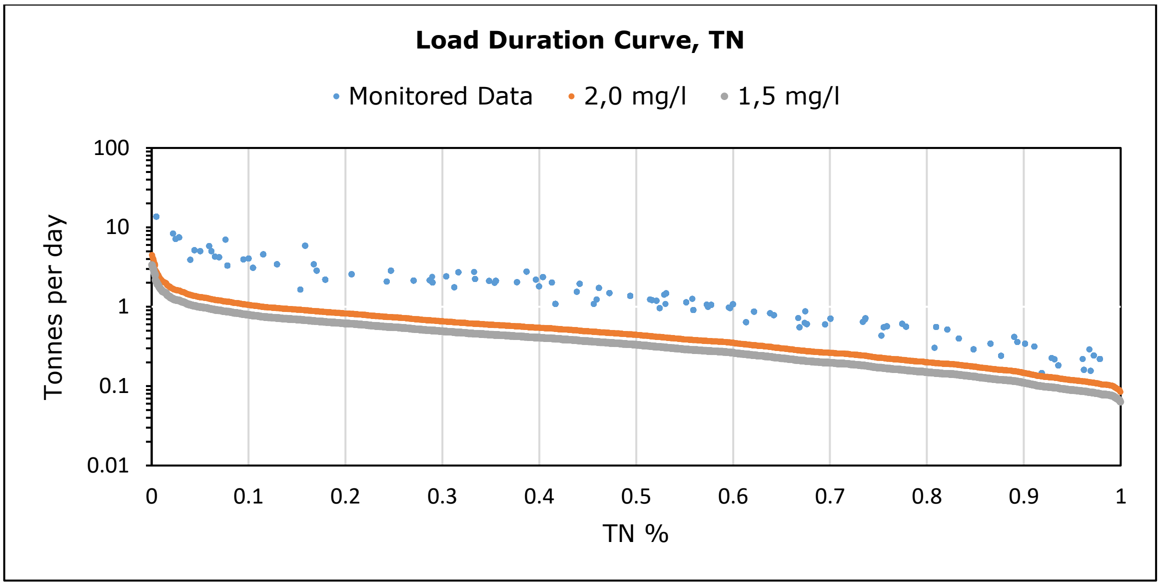


Figure 5.40: LDC for TN, Selja River

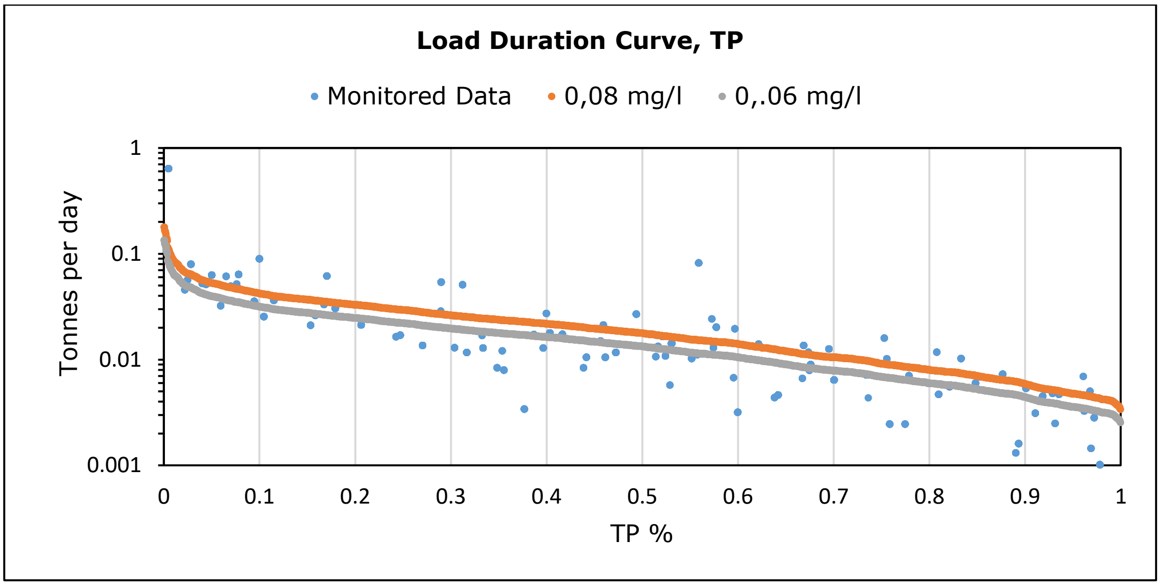


Figure 5.41: LDC for TP, Selja River

5.11 Kunda River

Kund River, the most water-rich river in Lääne-Viru, starts 1.5 km north of Roela town which is located on the eastern edge of the Pandivere Upland and the river flows into Kunda Bay. It has two major tributaries: Ädara River and Vaeküla River. There are five dams located in its watershed.

The stream flow regime is stable as it consists of spring water, and a major part of the river belongs to the Natura 2000 network [44].

The length of the river is 64 km, and with its additional branches the number extends to 82,2 km [42]. The river has an average flow of 4,42 m³/s.

The river has a total catchment area of 535,9 km², and the catchment area of the monitoring station is of 528 km². Most of the catchment area is forest with 59,1 % of it, then it follows agricultural land with 37 % and wetland with 2,4 % [40].

Monitored data

The complete data from the period of 1993 – 2019 was used for Kunda River.

The load inputs to the river gathered during that period were the following: For N, the minimum load input value was 0,42 mg/l, the maximum of 9,5 mg/l and had a mean input value of 2,3 mg/l. For P, the minimum value was of 0,01 mg/l, the maximum value was of 0,2 mg/l and it has a mean value of 0,03 mg/l. These values can be seen in Figure 5.42.

The data from the recorded inputs demonstrate that there is exceedance from N in the river. In terms of P, the mean value is below the lowest of the established limits, meaning that it does not possess any threat to the contamination of the river.

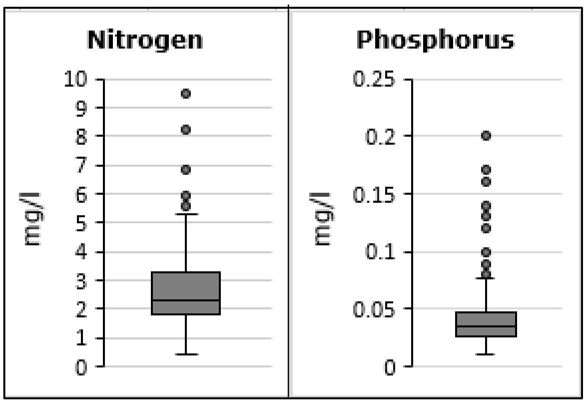


Figure 5.42: Mean content of N and P for Kunda River

When comparing these long-term data with the recorded data from a more recent period, 2009 – 2019, the trend for TN shows that the river is still under high risk as the mean is 2,6 mg/l, which is higher that the long-term mean value. For TP, the value has also increased but it is still under compliance with the targets as it recorded a mean value of 0,04 mg/l [40].

In the year 2018, the recorded input values for TN and TP were 2,8 mg/l and 0,02 mg/l [43]. These values show that the load inputs have maintained stable for TN, and although it shows a reduction from the mean value from the period of 2009 – 2019, it is still higher than the long-term mean and exceeds the established targets. For TP, the value has decreased in comparison to the mean values mentioned before, therefore there is no threat from the inputs of TP.

The Kunda River receives its highest flows during the month of April as shown in Figure 5.43.

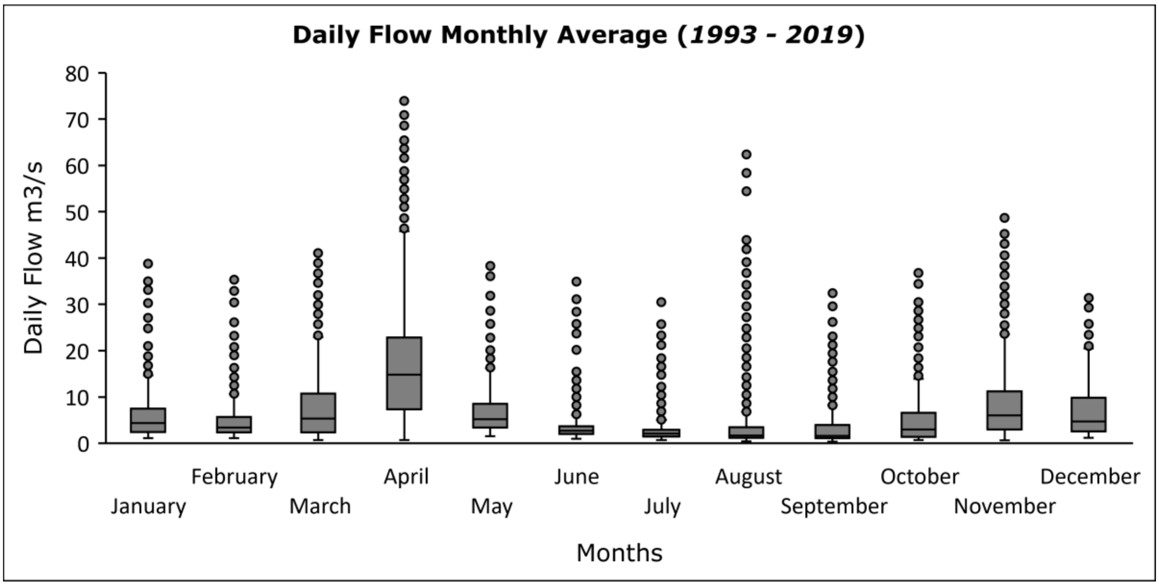


Figure 5.43: Daily flow monthly average, Kunda River

In Figure 5.44, the LDC of TN demonstrate that most of the recorded data are above the established target of 2,0 mg/l and therefore can be considered to possess a high risk to the river. It is noticeable that the monitored data is above the target throughout all seasonal variations meaning that point sources may have an impact in the inputs for TN. During low flows, there are recorded data that stands below the established targets.

For TP, the LDC show that most of the targets are below the established target, even when considering the lowest of the established limits (0,06 mg/l) as the target, therefore the Kunda River can be considered to be in good status in terms of TP inputs.

The mean value of the inputs arriving from point sources from the period of 2015 – 2019 are the following: 0,9 mg/l for TN and 0,0 mg/l for TP [40].

With the values of the mean point sources, it can be concluded that the agricultural sector is the one to be followed in terms of pollution in the Kunda River as the mean value of point sources for TN is lower than the mean values of the total inputs and there is no input for TP.

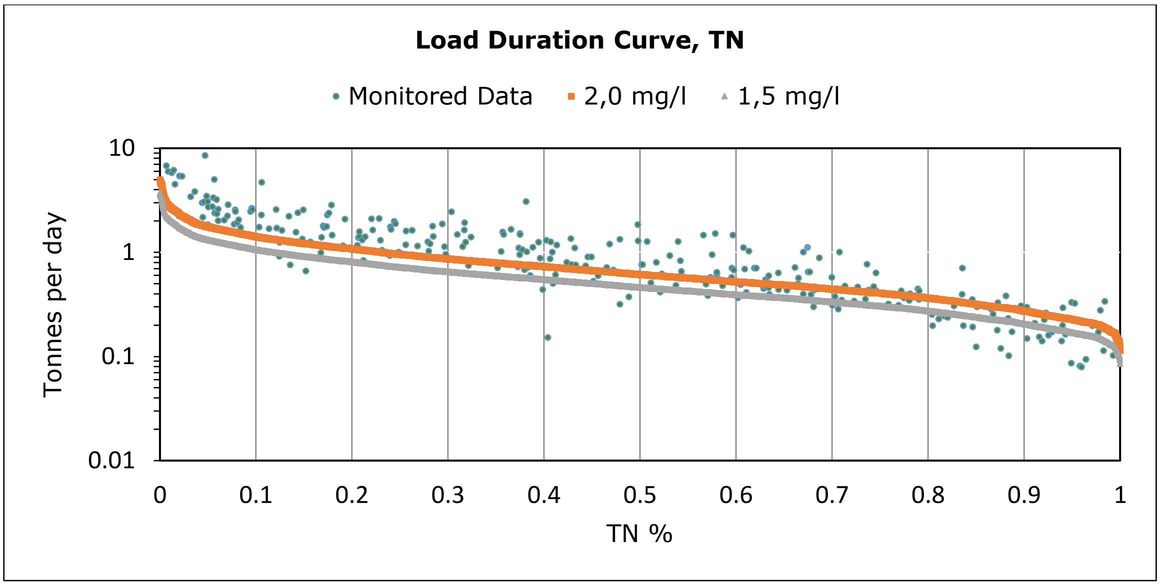


Figure 5.44: LDC for TN, Kunda River

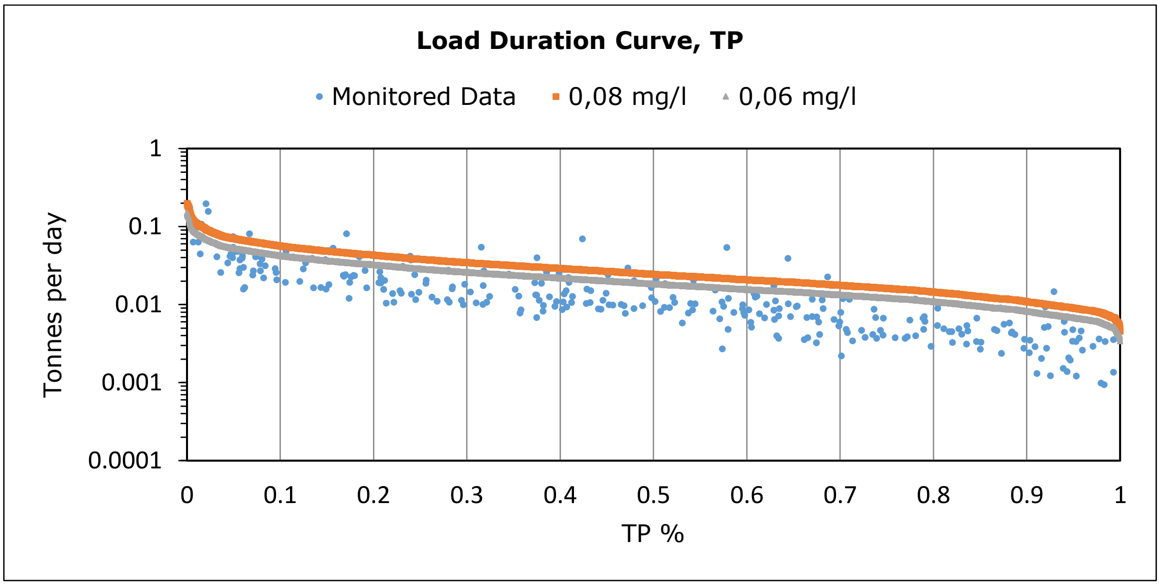


Figure 5.45: LDC for TP, Kunda River

5.12 Purtse River

Purtse River is in Ida-Viru and Lääne-Viru County and it has four major tributaries, these are: Hirmuse, Erra, Kohtla and Ojamaa. By the year 2009, there were nine closed and two operational oil shale mines in its watershed and it has a dam located at 4,9 km from the river mouth.

Purtse River does not belong to the Natura 2000 network [44].

The length of the main river is 51 km, and it extends to 57,2 km when adding its additional branches [42]. Purste river has an average flow of 6,56 m³/s.

The total catchment area of the river, and the catchment area of the monitoring station is 811 km². From this area, 66 % is covered by forest and 24 % is agricultural land, these are followed by wetland with 5,3 % and artificial influences with 4,8 % [40].

The quality of the water in the river improved since the 2000s as wastewater produced from the oil shale processing had been treated in a purification plant. After the purification process, the water is drained into the BS.

Monitored data

The complete data was gathered from the period of 1993 – 2019 for Purtse River.

The gathered data from the load inputs recorded data provided the following: For N, the minimum input value was of 0,42 mg/l, the maximum value was 11,2 mg/l, and the mean value was of 1,7 mg/l. For P, the minimum value was of 0,01 mg/l, the maximum recorded data was of 1,8 mg/l, and the mean value was 0,02 mg/l. These figures can be seen in Figure 5.46. The asterisk symbol means besides Phosphorus means that the highest value (1,8 mg/l) has been omitted from the box and whiskers plot for a better representation of the recorded.

These mean values show that in both cases, for N and P, the values are under compliance with the highest of the established targets (2,0 mg/l and 0,08 mg/l). Although this can determine the quality of the water is in good status, when considering the mean of TN and the lowest of the established targets (1,5 mg/), it is seen that the mean is in exceedance and therefore needs reduction. For P, the value is under compliance with its lowest target 0f 0,06 mg/l.

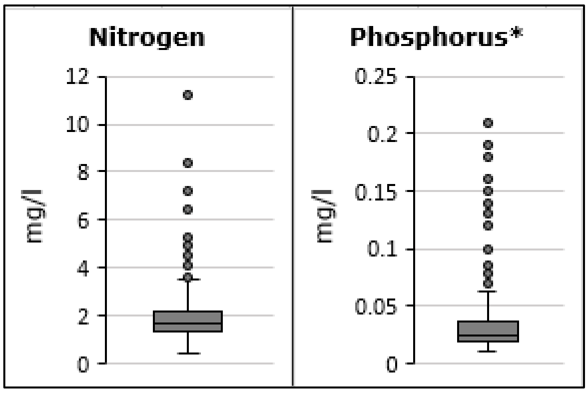


Figure 5.46: Mean content of N and P for Purtse River

If we compare these long-term means with the mean of the recorded data from the period of 2009 – 2019 in Tables 4.3 and 4.4, it shows a reduction in terms of N but an increment for P, the recorded data for this period was the following: 1,4 mg/l for N and

0,03 mg/l for P [40]. Both numbers show compliance with the lowest of the established limits.

When comparing these data with the recorded value on 2018, a significant reduction can be seen for TN and TP as the values for that year were 1,1 mg/l for TN and 0,01 mg/l for TP [43].

In Figure 5.47, it is seen form the long-term daily flow monthly average that the Purtse River receives its highest flows during the month of April.

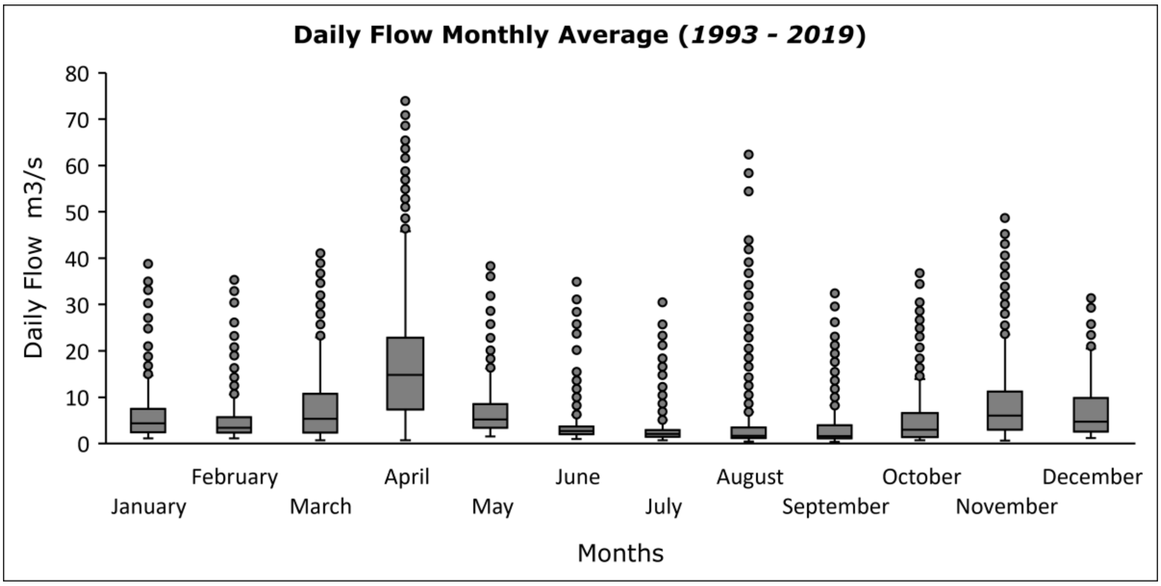


Figure 5.47: Daily flow monthly average, Purtse River

In the LDC for TN in Figure 5.48, the exceedance occurs throughout all the seasonal variations, meaning that there are point sources discharging which are significantly affecting the quality of the water. Although the exceedance occurs during all year, during high flows all the recorded data is above the target line, different than during low flows where most of the data is under the target line. For these reasons, it can be assumed that there the agricultural sector is impacting the quality at significant levels.

In terms of TP, most of the recorded data are situated below the target lines, even when considering the lowest of the target values the TP inputs seem to be in good status and therefore do are of risk to the quality of the river.

The mean values of the point sources from the period of 2015 – 2019 show a high value for TN, 21,4 mg/l, which exceeds by a significant amount the value of the established target. For TP, the mean value was of 0,5 mg/l which is also in exceedance with the target values [40], which can explain the few exceedance points throughout the seasonal variations. Therefore, it can be determined that point sources are affecting the quality of the water in Purtse River and must be assessed in order to reduce its negative impact.

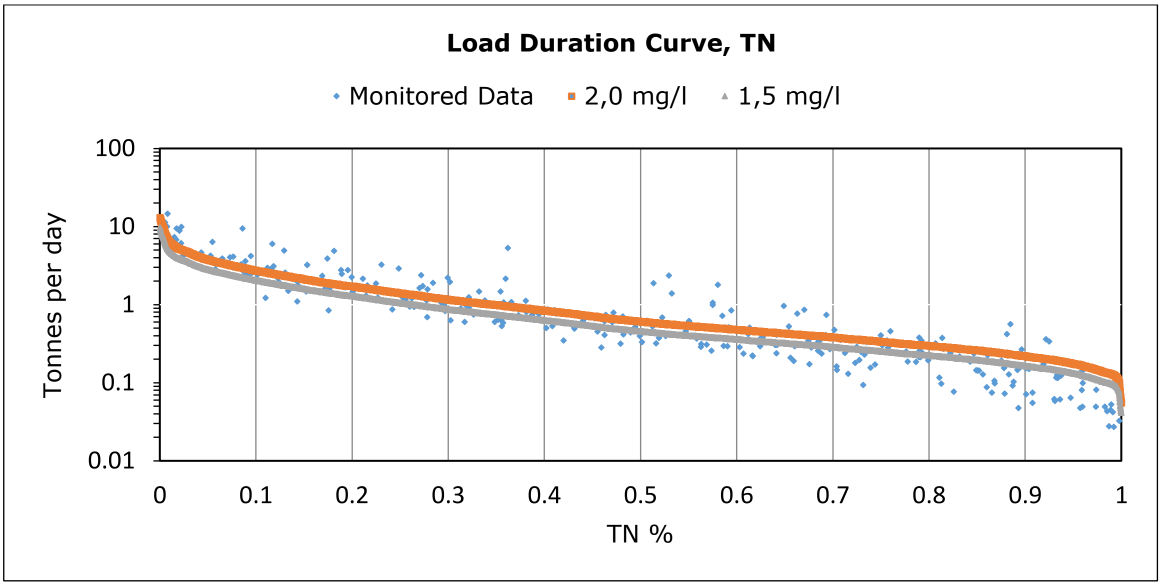


Figure 5.48: LDC for TN, Purtse River

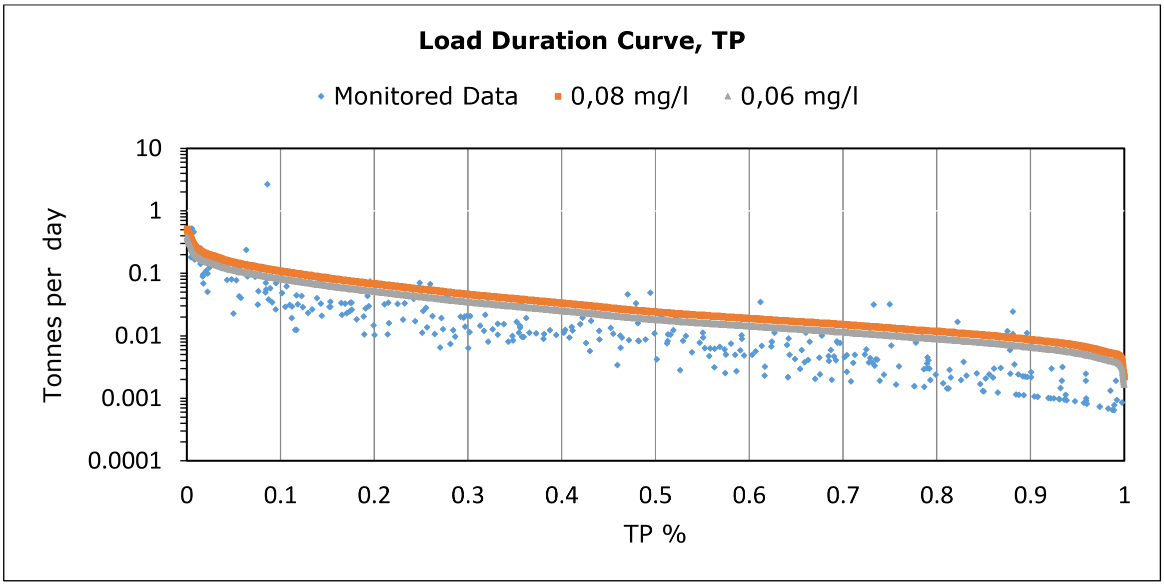


Figure 5.49: LDC for TP, Purtse River

5.13 Pühajõgi (River)

Pühajõgi belongs to the Viru sub-basin of the East-Estonian river basin district and is the upper course of the River Võhandu. The river starts near Kukruse and flows into the Gulf of Finland in Toila. Its main tributaries are Rausvere and Vasavere river.

The river has a length of 36,4 km, and has an average flow of 1,85 m³/s. The total catchment area of the river, and the catchment area of the monitoring station is 220 km² [46].

Monitored data

The daily flow available data for Pühajõgi includes the time period of 2008 – 2019.

During that period, the monitored input load data was the following: For N, the minimum value was 0,51 mg/l, the maximum value was 5.3 mg/l, and the mean value was 1,5 mg/l. For P, the minimum value was of 0,01 mg/l, the maximum value was 0,38 mg/l, and the mean value was 0,05 mg/l. These recorded values can be seen in Figure 5.50.

The mean values for both TN and TP are under compliance even when considering their lowest established targets of 1,5 mg/l and 0,06 mg/l. For this reason, the river can be considered to have a good status.

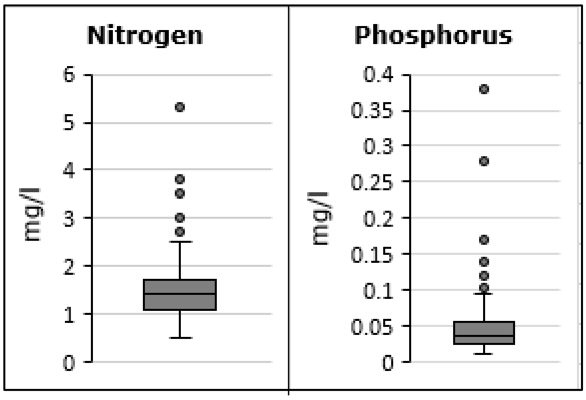


Figure 5.50: Mean content of N and P for Pühajõgi (River)

The study period made for Pühajõgi is like the study that concluded in the data from Tables 4.3 and 4.4, therefore it is not necessary to apply a comparison.

Although it is necessary to see the monitored data from the year 2018, these values are: 1,6 mg/l for TN and 0,03 for TP [43]. If we consider the lowest of the targets for TN, the 1,6 value is in exceedance and therefore needs reduction. For TP, the value has reduced, and it still stands below the lowest of its established targets.

In Figure 5.51, the daily flow monthly average shows that the highest flows occur during the month of April.

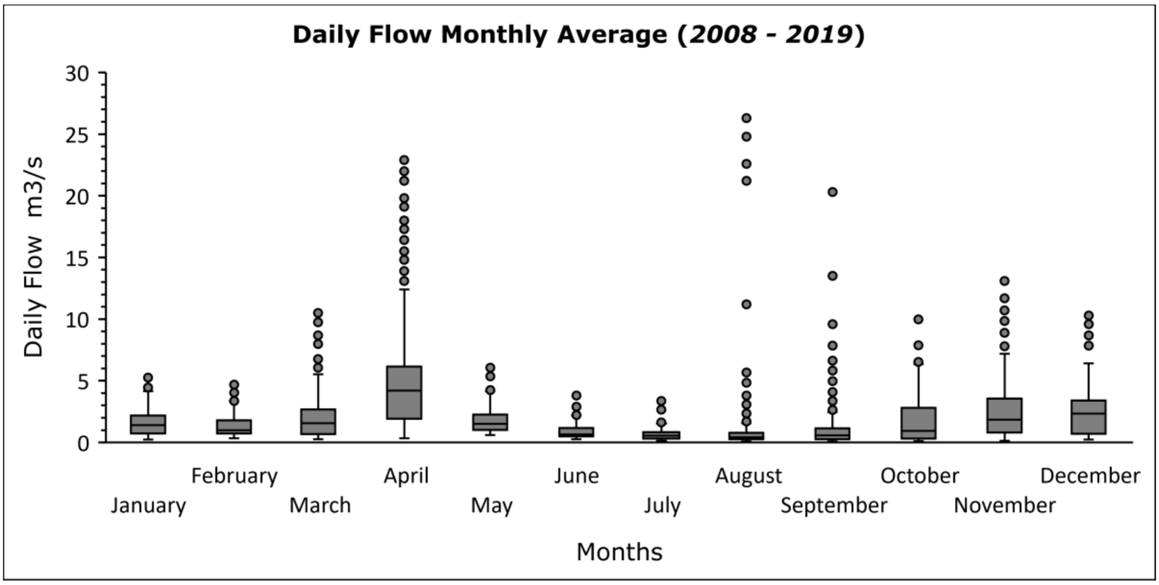


Figure 5.51: Daily flow monthly average, Pühajõgi (River)

In Figure 5.52, the LDC for TN makes it noticeable that the river is in compliance with the loads limits as most of the values are under the limit line throughout all the seasonal variations. Due to the location of the monitored values (moist conditions) that are above the target line, it can be assumed they are from non-point sources.

Same is the case for TP, most of the monitored values are in compliance with the targets and appear to be below the target line in the LDC.

For the mean point sources value from the period year of 2015 – 2019, the values appear to be high for both, the recorded values were the following: 2,5 mg/l for TN and 0,1 mg/l for TP [40]. Meaning that point sources need reduction in order to not make a significant damage to the quality of the water in the river.

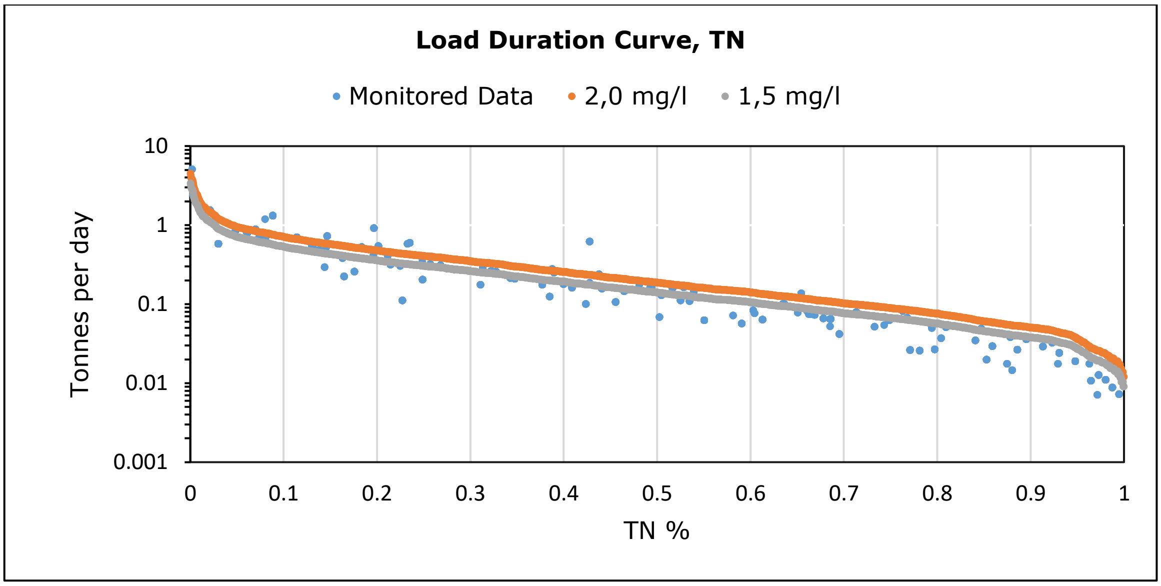


Figure 5.52: LDC for TN, Pühajõgi (River)

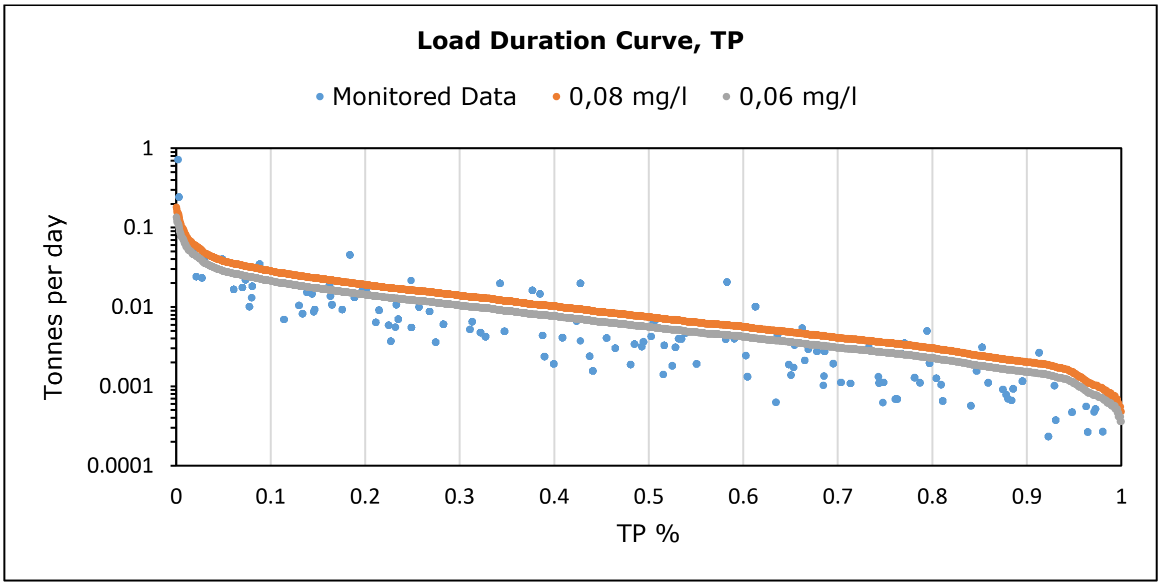


Figure 5.53: LDC for TP, Pühajõgi (River)

5.14 Narva River

Narva river, the largest river in Estonia, is located between Estonia and Russia, its fairway constitutes as the political boarder between the two nations.

The Plyussa River is the largest of its tributaries, and due to the natural regulation of flow from the Lake Peipsi, floods almost never occur in the Narva River and it also prevents it from drying out [47]. The quality of the water at the Narva River is largely determined by the Lake Peipsi.

The river is 77 km long and when adding its additional branches, it is 123,9 km long [42]. The average flow of the Narva River is of 440,86 m³/s.

From its total length, about 30 km has been dammed at Narva Water Reservoir. The hydrographic catchment area is 56,783 km² and it is divided by countries as follows: 35,985 km² in Russia, 3,599 km² in Latvia, and 17,199 km² in Estonia.

Monitored data

For the monitored station located in the city of Narva (near the GUF) the data of the daily flow was available for the period of 2003 – 2019. For the load inputs, the complete data from 1993 – 2019 was available.

Different from the other rivers studied in this thesis, the Narva River has a different criterion, these are the following: 0,7 and 0,5 for TN and 0,06 and 0,04 for TP.

The information gathered for this period of the input loads was the following: For N, the minimum value was 0,09 mg/l, the maximum value was of 2,1 mg/l, and the mean was 0,61 mg/l. For P, the minimum monitored data was of 0,01, the maximum of 0,19 mg/l, and the mean of 0,04 mg/l. The values can be seen in Figure 5.54.

These mean values mentioned above show compliance with the highest of the established targets for both TN and TP. In the case of TN, if we considered the lowest of the targets (0,5 mg/l), the mean value will be in exceedance and therefore in need of reduction. For TP, even when considering the lowest of the targets (0,04 mg/l) the mean value will be the same as the limit and can be considered in good status.

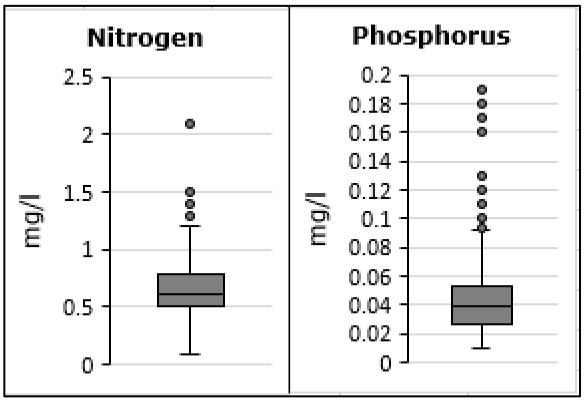


Figure 5.54: Mean content of N and P for Narva River

When comparing these long-term mean values to the values of a more recent time period, 2009 – 2019, it becomes evident that there has not been a significant change in terms of TN as the mean value for this time period is 0,7 mg/l, meaning that even when considering the lowest of the established targets (0,5 mg/l) the mean value is still in exceedance and would need reduction. For TP it shows a reduction in the mean with a value of 0,03 mg/l during that same period, meaning that it is under both limits [40].

In Figure 5.55 the daily flow monthly average show that the Narva River has its highest flows during the month of April.

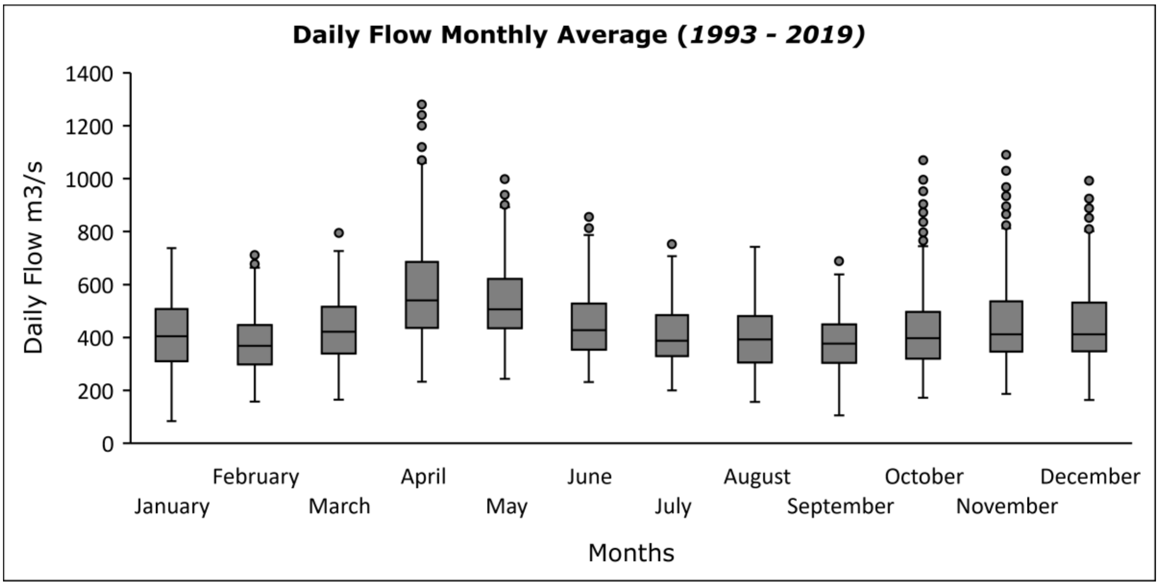


Figure 5.55: Daily flow monthly average, Narva River

In Figure 5.56, the LDC for TN shows that about half of the monitored values are places above the target and the other half below the target when considering 0,7 mg/l as the target value. When considering 0,5 mg/l the case is different as most of the monitored values appear to be above the target line meaning and can be considered to be in bad status. Another point to notice is that the values are spread throughout all the seasonal variations, even at low flows, meaning that there are point sources involved in the TN inputs in the river.

For TP, loads are mostly under the highest established target (0,06 mg/l) line meaning that they are under compliance and can be considered as in good status. It is different when considering 0,04 mg/l as the target as it can be seen some monitored values throughout the different seasonal variations that are above the target, meaning it needs reduction.

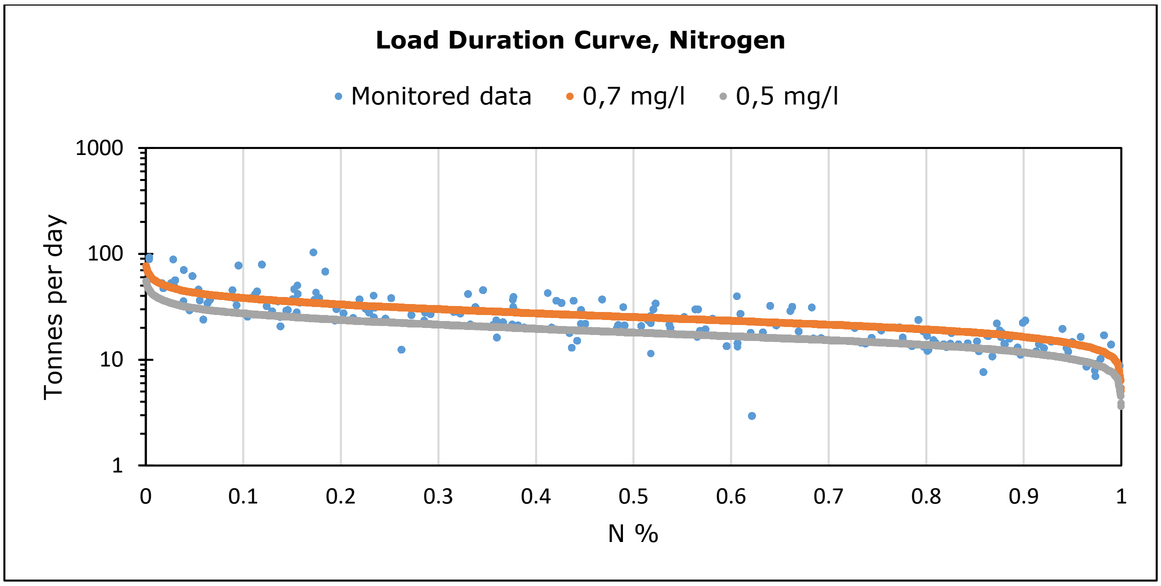


Figure 5.56: LDC for TN, Narva River

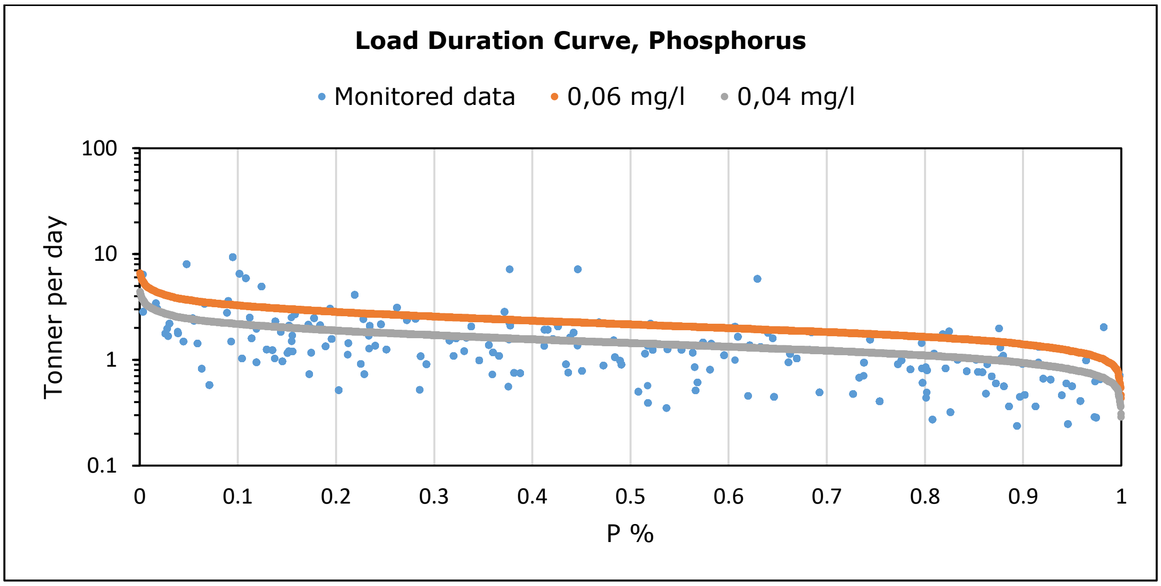


Figure 5.57: LDC for TP, Narva River

6 SUMMARY

Excessive input of organic matter, N and P, into the BS marine environment causes eutrophication, leading to the degradation of the water body. The HELCOM contracting parties have been working on improvements and the betterment of the BS, and for this reason it is important to implement continuous monitoring and assessments in the contracting parties' waterbodies.

The TMDL is an important plan of action to calculate the maximum amount of pollutant loads that a waterbody can absorb and still achieve the waterbody quality standards. In the area of the BS, these studies are of importance as most of its sub-basins have not achieved the quality standards stated by the BSAP. In the case of the GUF, none of the nutrient load targets (for N and P) have been achieved. Constructing an LDC provides an insight of the quality of the waterbody in terms of the nutrient inputs for a specific period, and with this information, the needed reductions targets can be established.

Riverine input loads must be reviewed and assessed as by 2014, 79,3 % of the nutrient inputs to the GUF enter through rivers. In the case of TN and TP inputs for Estonia during that same year, the riverine inputs were 87,5 % and 92,6 % for TN and TP, respectively. These numbers demonstrate why Estonia must take a serious action in controlling the pollution in its rivers.

After gathering the available data from the period 1993 – 2019 of the studied Estonian rivers and their monitored concentrations for TN and TP, it was seen that most of the rivers were in bad status for TN, to be more specific, 8 of the 14 rivers had a mean value above the 2 mg/l target (highest of the established targets for this thesis). In terms of TN, special focus must be put on Selja, Loobu, and Vääna as these rivers mean values resulted to be in high above the target. For TP, the case was different as only one of the 14 studied rivers (Vääna River) was above the established target.

From the LDC of the rivers that had exceeded the established targets there was a trend where it showed exceedance throughout all the different seasonal variations, meaning that there are point sources as the main contributors of the input loads. Adding to point sources, which can be controlled with better regulations (as seen in that past), the agricultural sector must also be controlled as the different practices can make a significant impact in the waters.

By the gathered data, is it evident that Estonia must act to decrease the level of pollution in its rivers to achieve the national targets and contribute to the improvement of the BS and consequently the GUF.

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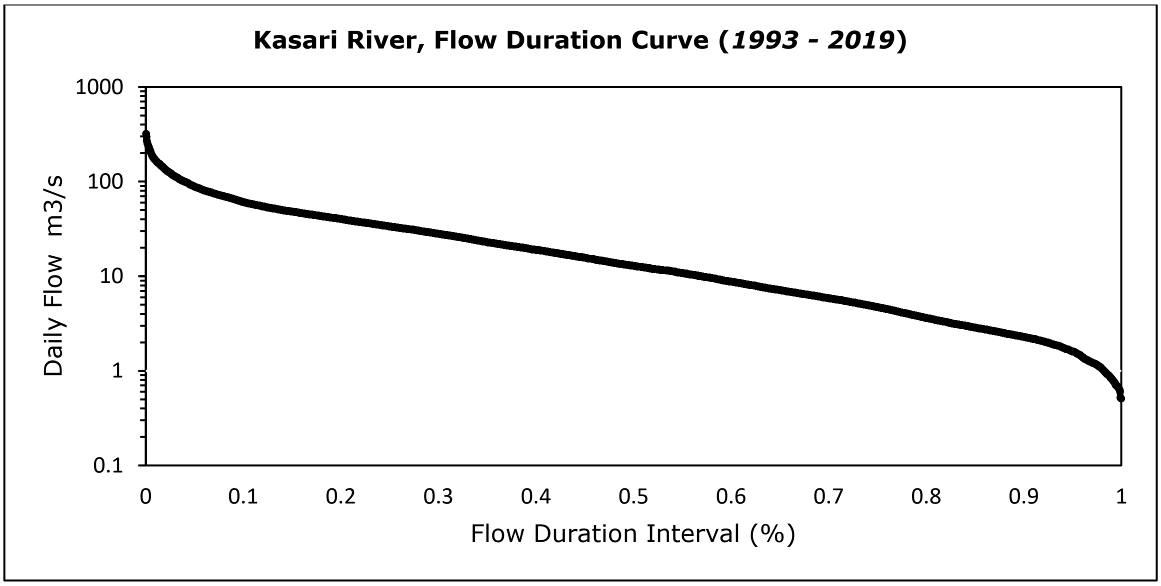
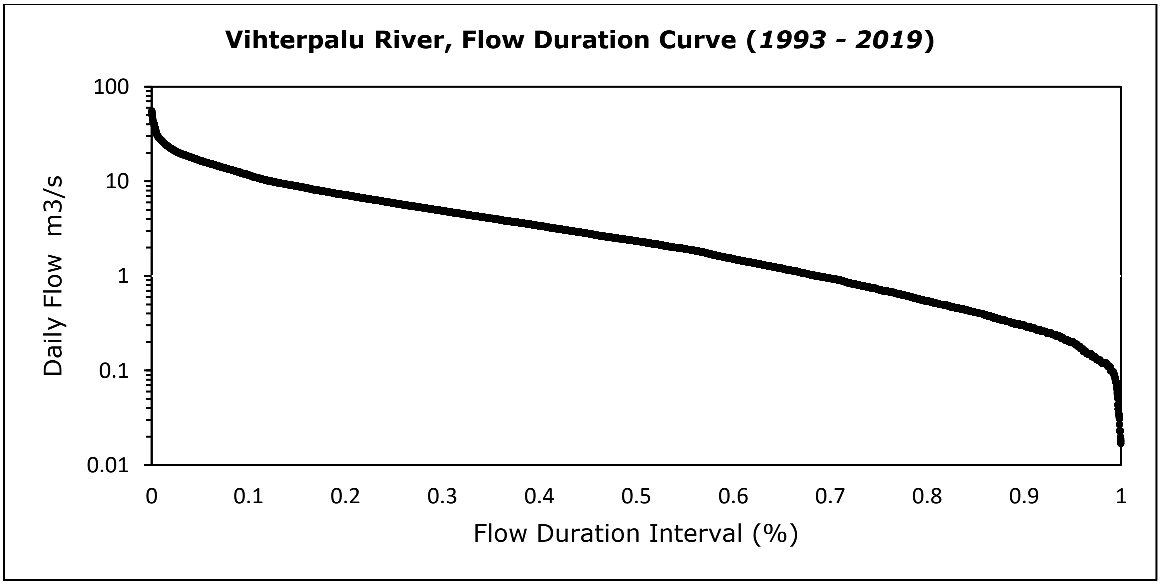
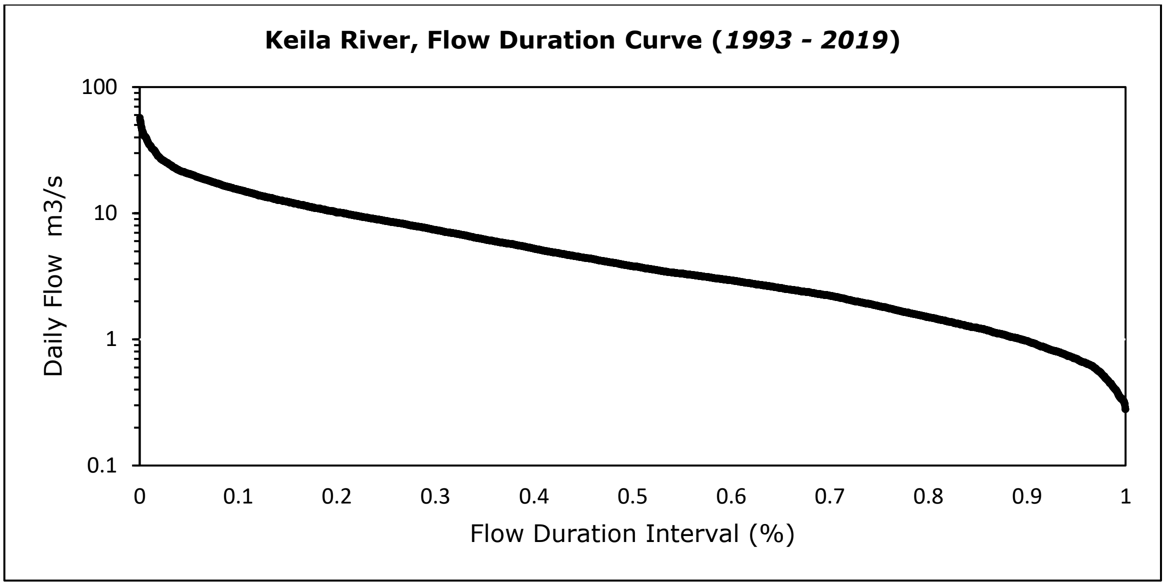
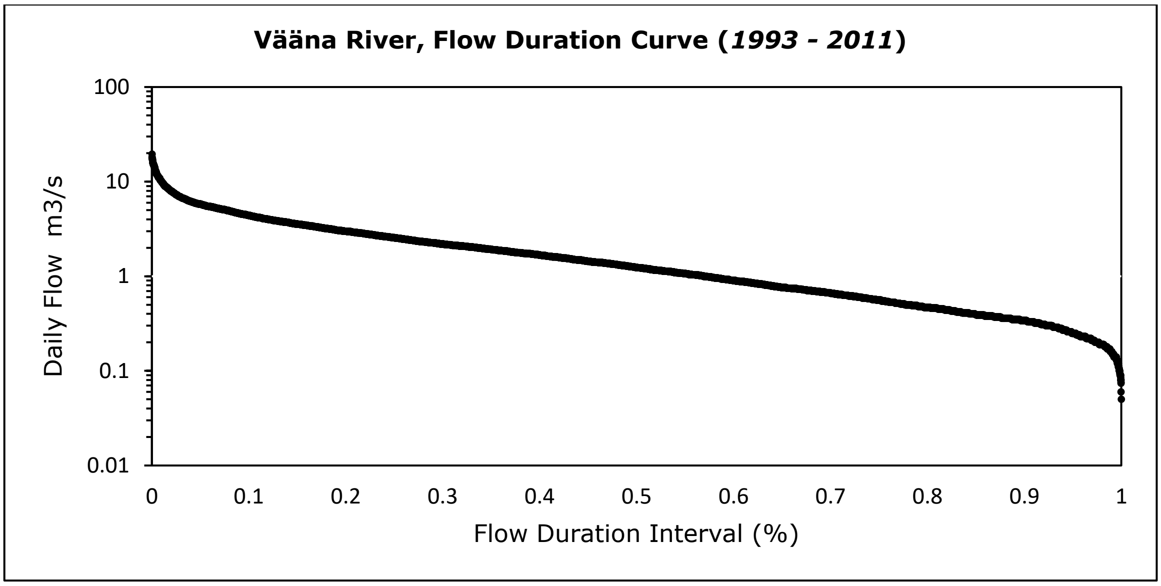
8 APPENDICES

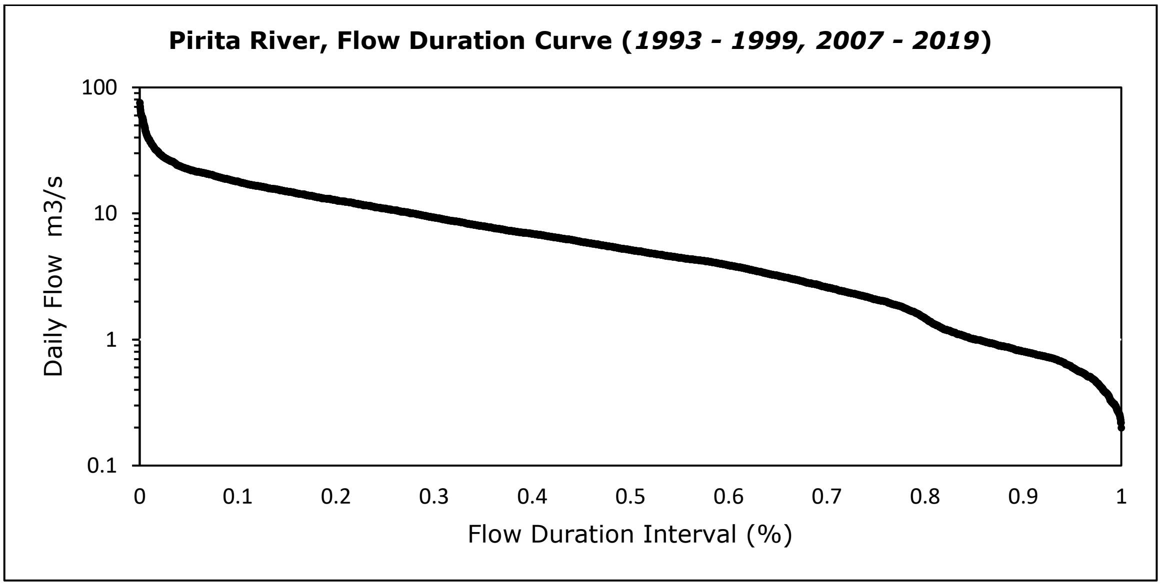
8.1 Flow Duration Curves for studied rivers

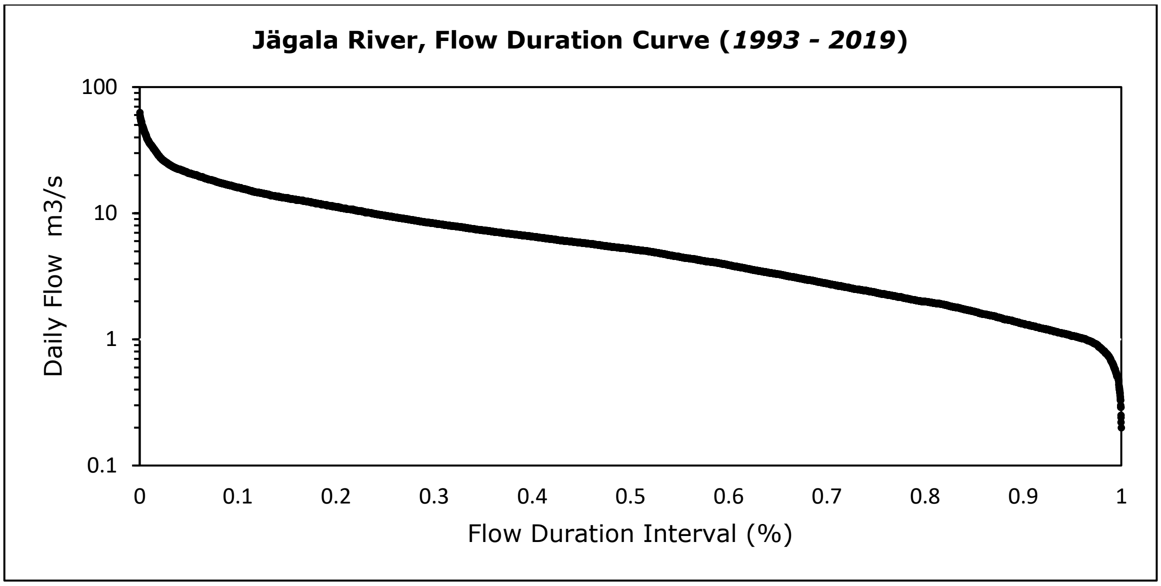


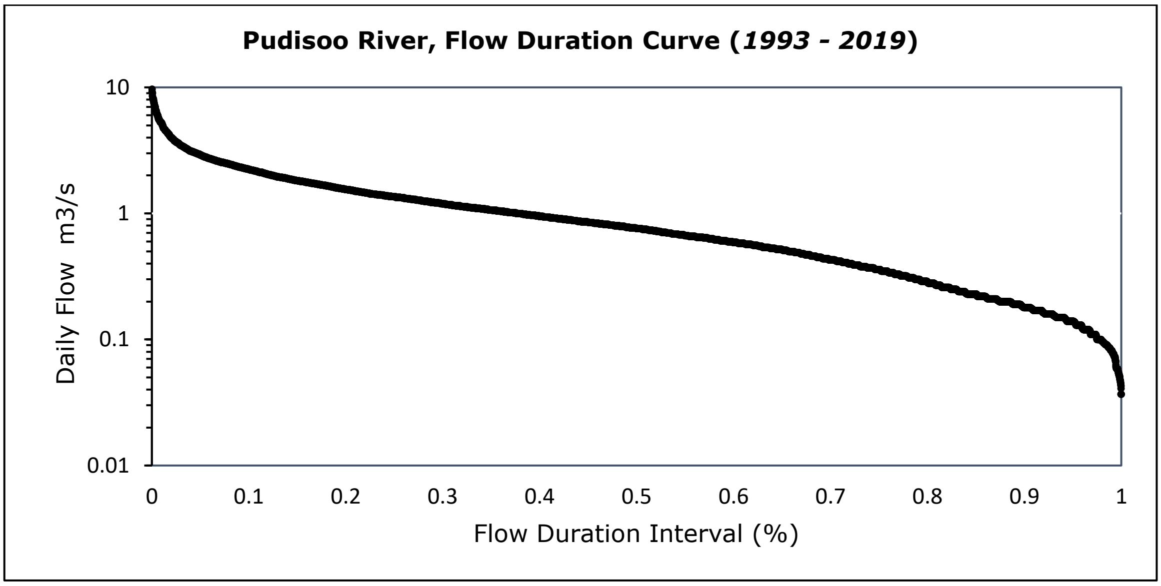


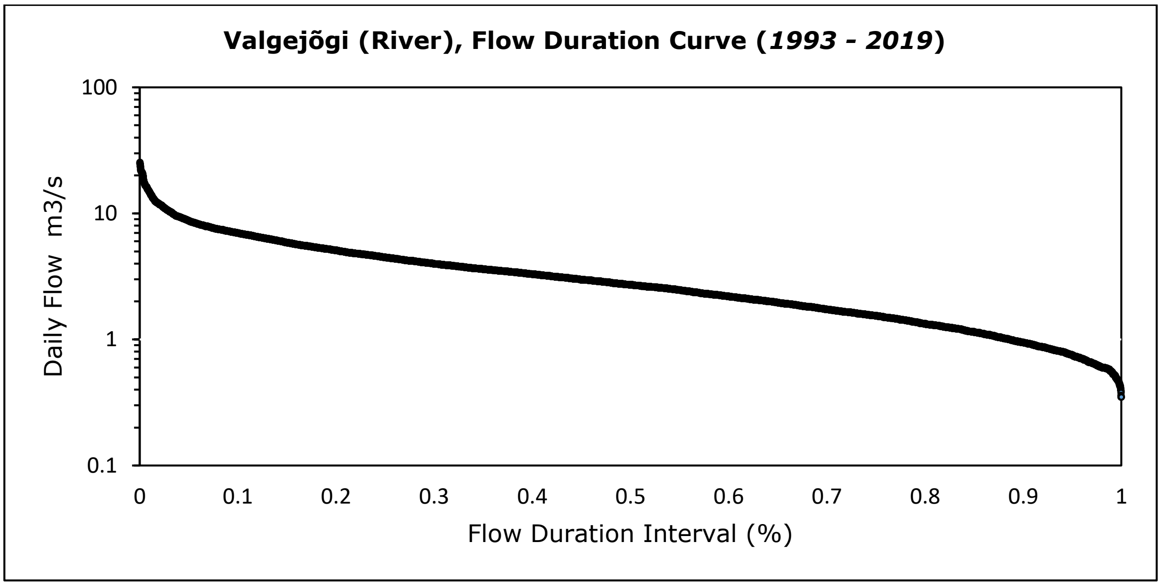

Keila River, Flow Duration Curve (*1993 - 2019*)
100
10
1
0.1
Daily Flow m3/s
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)

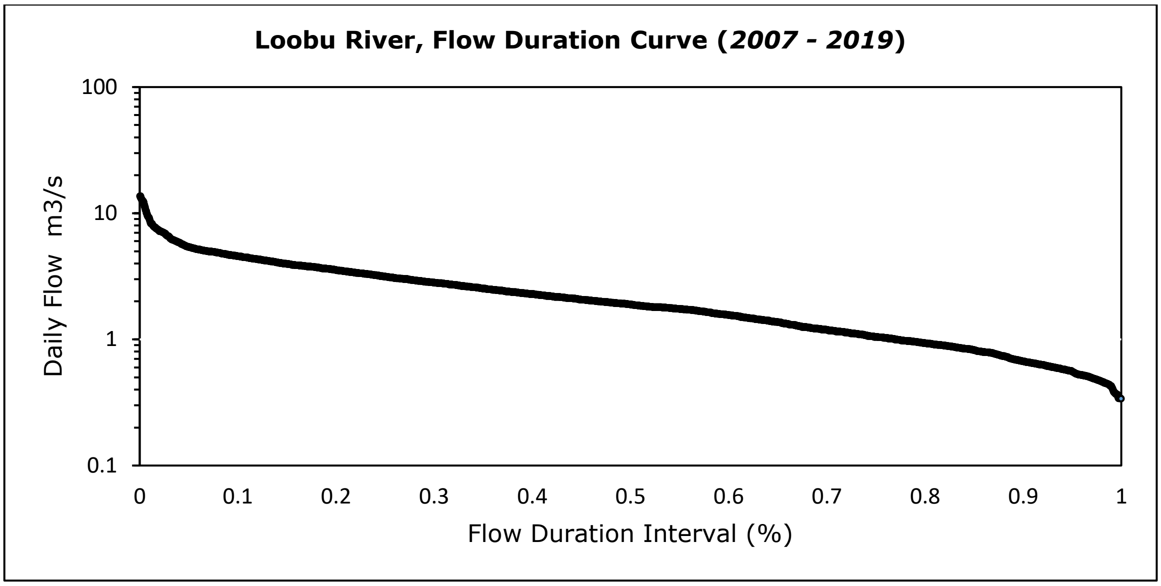

Vääna River, Flow Duration Curve (*1993 - 2011*)
100
10
1
0.1
0.01
Daily Flow m3/s
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)

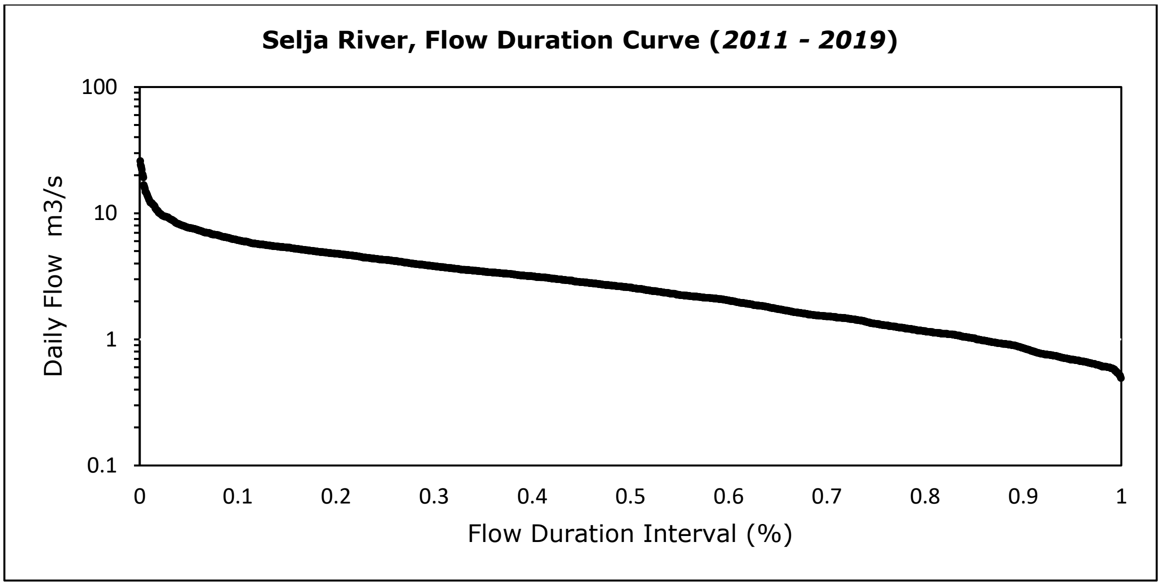

Pirita River, Flow Duration Curve (*1993 - 1999, 2007 - 2019*)
100
10
1
0.1
Daily Flow m3/s
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)

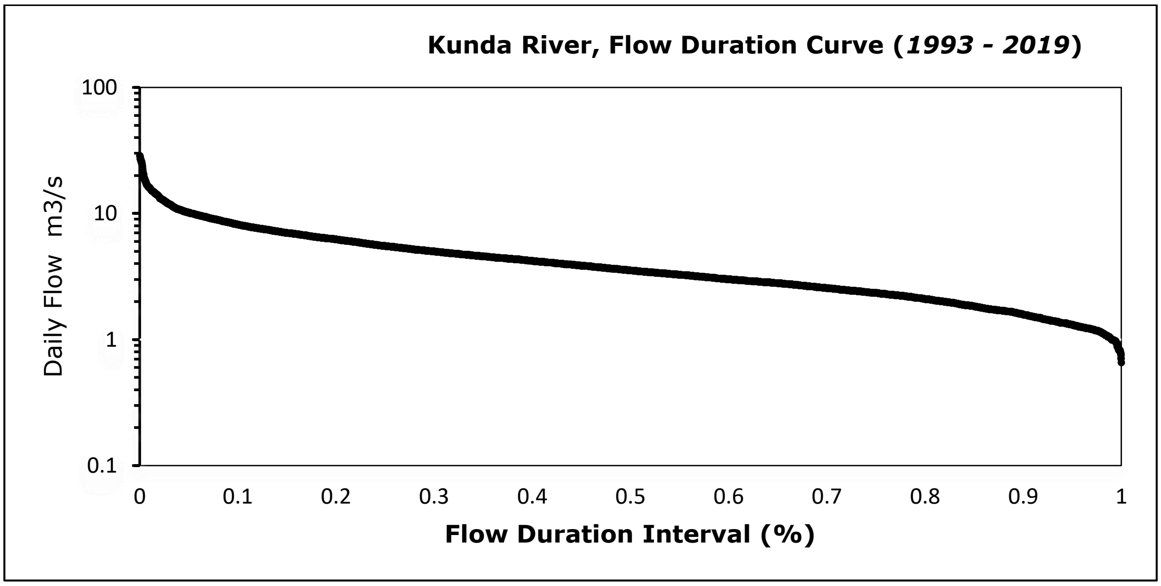

Jägala River, Flow Duration Curve (1993 - 2019)
Daily Flow m3/s
100
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)

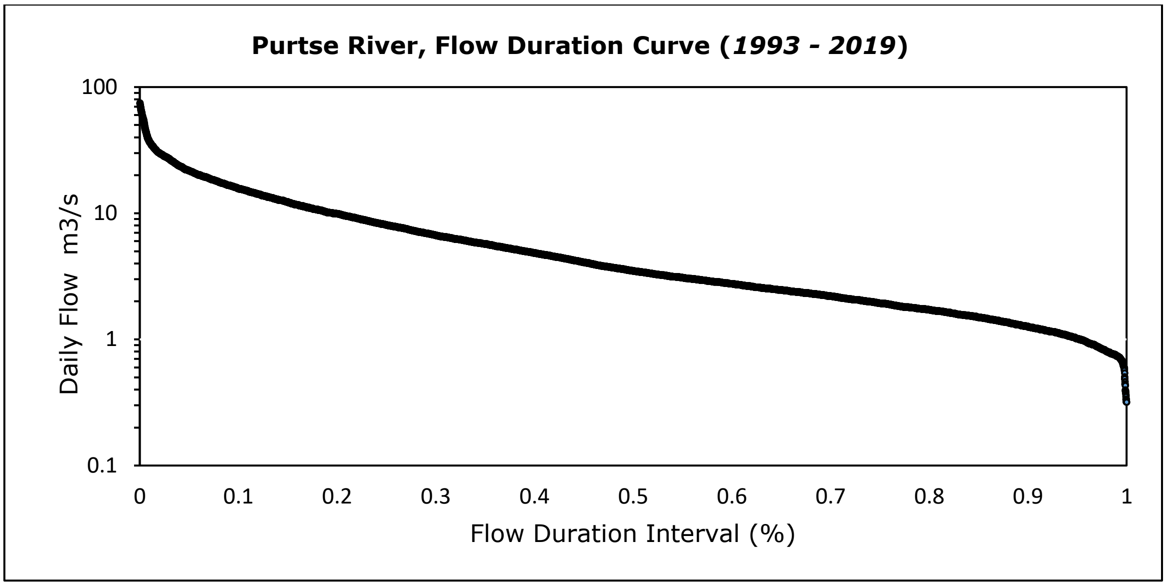

Pudisoo River, Flow Duration Curve (1993 - 2019)
Daily Flow m3/s
10
1
0.1
0.01
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)

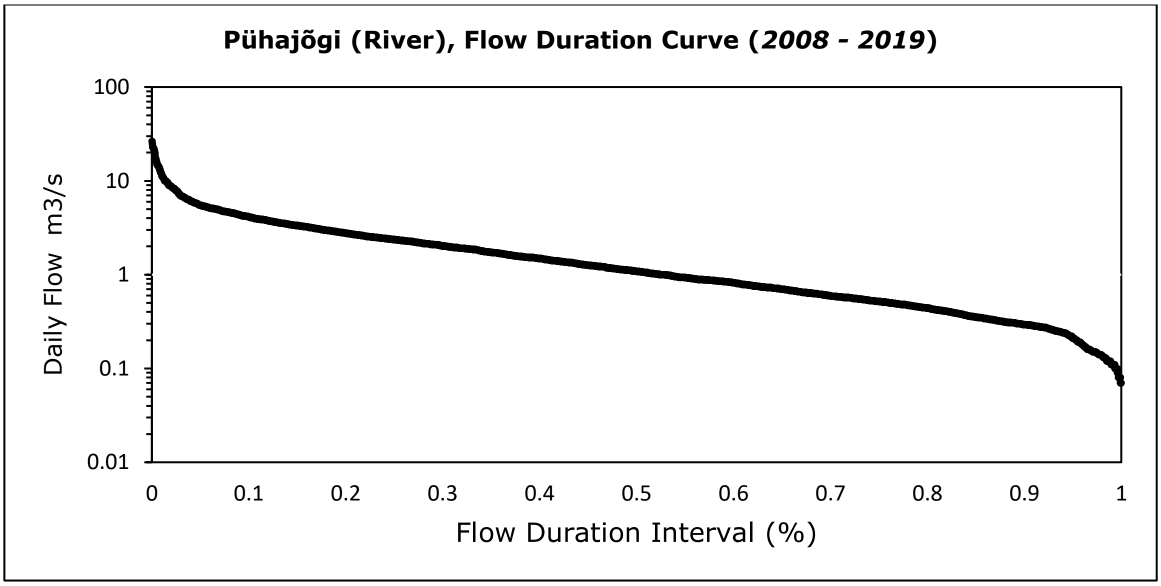

Valgejõgi (River), Flow Duration Curve (1993 - 2019)
Daily Flow m3/s
100
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)

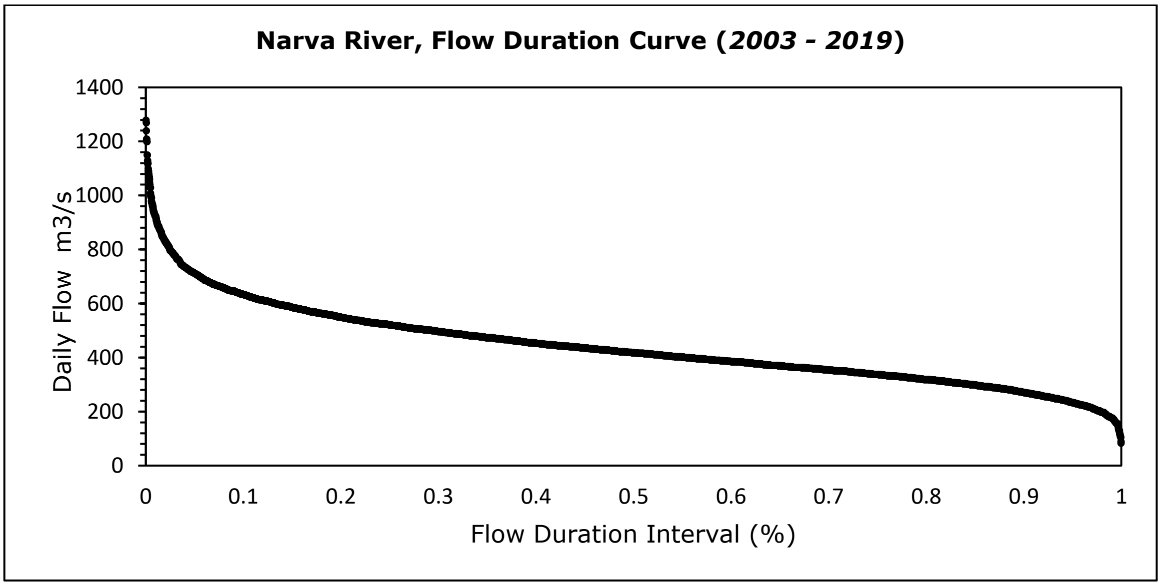

Loobu River, Flow Duration Curve (2007 - 2019)
Daily Flow m3/s
100
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)


Selja River, Flow Duration Curve (2011 - 2019)
Daily Flow m3/s
100
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)


Kunda River, Flow Duration Curve (1993 - 2019)
Daily Flow m3/s
100
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)


Purtse River, Flow Duration Curve (1993 - 2019)
Daily Flow m3/s
100
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)


Pühajõgi (River), Flow Duration Curve (2008 - 2019)
Daily Flow m3/s
100
10
1
0.1
0.01
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)


Narva River, Flow Duration Curve (2003 - 2019)
Daily Flow m3/s
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Duration Interval (%)