Daily Allowable Maximum Loads to decrease nutrient load to the Gulf of Riga (DAML)

Report of the Activity T1

Development, testing and promotion of a novel methodology for Estimation of Daily Allowable Maximum Loads (DAML) of pollutants to decrease nutrient load to the Gulf of Riga

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Content

1. Introduction

Water is the most important natural resource on our planet and the quality of water should be a concern for all of us. According to Water Framework Directive 2000/60/EC (WFD, 2000) requirements, all European countries should ensure achievement of at least good ecological status in their waters.

The Gulf of Riga is a relatively narrow and isolated region of the Baltic Sea. In the east and south it borders on the coasts of Estonia and Latvia, while in the north it is sheltered by the islands of Saaremaa and Muhu. It is separated from the waters of the Baltic Proper by numerous shoals and islands. The gulf has an area of 16,330 km^2 and a volume of 424 km^3. It is relatively shallow, its greatest depth being 60 m and the average depth of the Gulf of Riga is 30 m (Stigebrandt ja Wulff, 1987). These conditions determine relatively high concentrations of nutrients in the Gulf that exceed the level in the open sea by two times (Martin, 2017[1]). Saline waters entering the gulf from the open Baltic Sea mix with fresh water brought by the rivers flowing into the bay. The salinity is 4−6 PSU in the east part and 5−7 PSU in the west part of the Gulf (GURINIMAS, 2019).

The waters in the Gulf of Riga are eutrophic: nutrients enter the gulf by the rivers, direct discharges of sewage and also by exchange from the Gotland Basin. Water quality of rivers discharging to the bay is highly impacted by economic activities both in Estonia and in Latvia. The good status for the gulf, including coastal waters is, therefore, not yet achieved. Excess nitrogen and other nutrients have effects not only to water systems, but also to terrestrial systems and atmosphere expressed, for example, by ozone induced injuries to crops, acidification and eutrophication effects on forest, soils and freshwater aquatic systems, leaching, eutrophication and hypoxia in coastal and lake ecosystems (GURINIMAS,2019).

Measures to cut the nutrient load have been targeted to agricultural, industrial, energy sectors and urban areas that are the main sources of nutrient in the Gulf of Riga catchment area (GURINIMAS, 2019). HELCOM (2018a) estimates show that in 2014 input of total nitrogen and total phosphorus to the Gulf of Riga was 83 000 and 2 300 tonnes, respectively. Riverine transport is the most important pathway for input of nutrients comprising 87% of total nitrogen load and 97% of total phosphorus load to the Gulf of Riga in 2014. Riverine nutrient loads are highly dependent on the river discharge. In the case of Latvia, the total load of nutrients to the Gulf of Riga is also affected by transboundary nutrient inputs from Lithuania, Belarus, and Russia (GURINIMAS, 2019).

The status of the Gulf of Riga with regard to nutrients is bad or even very bad in the Pärnu Bay area. The reduction of nutrient input is utmost important to reach at least good ecological quality in the Gulf of Riga (HELCOM, 2018b; GURINIMAS, 2019). Therefore, the project aimed to test a methodology for quantification of maximum riverine daily loads of nitrogen and phosphorous to the Gulf of Riga in selected river catchments (Salaca and Pärnu) and sub-catchments to achieve the target. A list of suitable mitigation measures for selected pollutants are proposed based on the study results. The Pärnu river has been selected for research because it is the largest stream discharging to the Gulf of Riga in Estonia and contributing lots of nutrients to the bay. Salaca river is one of the biggest rivers in Latvia and it has the biggest river catchment in northern Latvia that is located next to Estonia and Pärnu river basin. Salaca river basins are shared between Latvia and Estonia. It is essential for both countries to contribute to assessment of ecological status of transboundary water bodies jointly (WBWB, 2020).

Ecological status of water bodies, water quality and nutrients has already been research subjects for both countries in close cooperation in other European Union projects. In close cooperation project partners is continuing to claim good quality of waterbodies both in Latvia and Estonia.

2. Physico-geographical description of the river catchments

2.1. Physico-geographical description of the Salaca and Seda river catchment

Geology, geomorphology, and soils

Salaca River (Estonian: Salatsi jõgi) starts from Lake Burtnieki and flows to the Gulf of Riga. The catchment area of the Salaca River includes watersheds of Lake Burtnieki that consists of Seda, Ruja, Briede river basins as well (Fig. 2.1.1.).

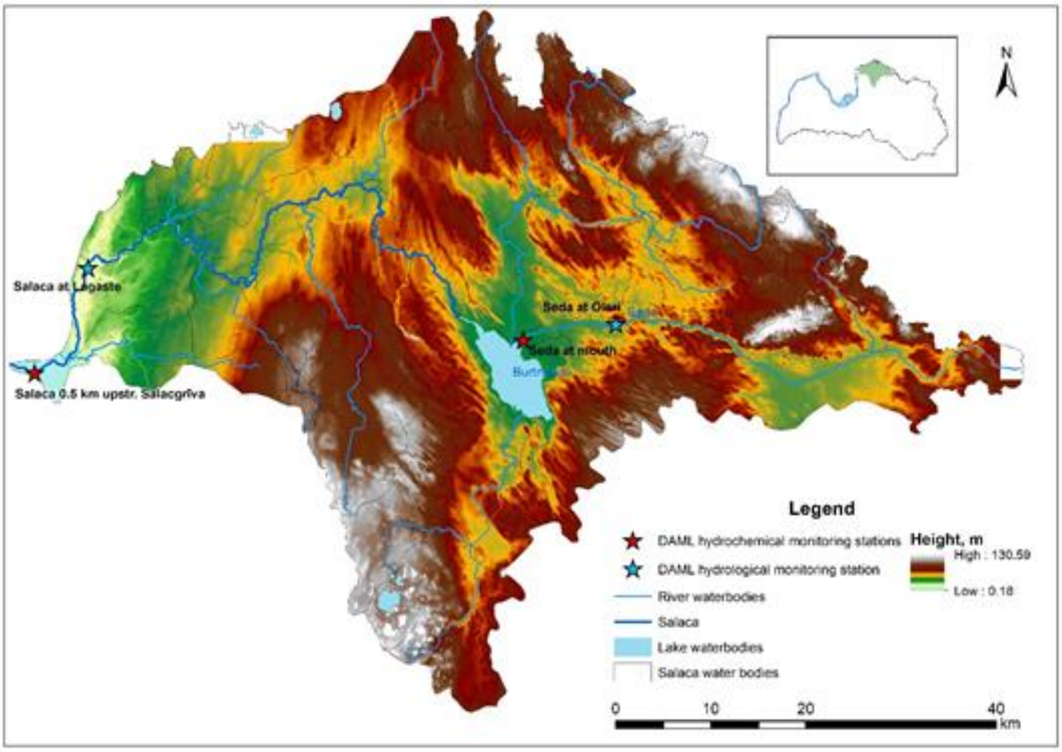


Figure 2.1.1. Physical map of Salaca River Basin (LĢIA, 2019; LEGMC, 2021).

The Salaca River Basin is located in the North Latvian Plain turning into the Coastal lowland at the mouth part. The elevation of the North Latvian Plain is 40-60 meters above sea level (a.s.l.). The highest elevation in mentioned watershed is found at altitude more than 100 meters a.s.l. where the highest point of Seda River basin (104.70 meters a.s.l.) is located. The landscape consists of small hills, swamps and many drainage channels.

The upper part of the geological section (zone of groundwater active exchange) consists of Quaternary and Devonian sediments. Their total thickness varies mainly over a wide range from 80 m in the north-western part of the Salaca River Basin to 180 m in the southern part of the basin, in some places it increases up to 216 m.

The thickness of Quaternary sediments varies from 10 to 50 m, but the incisions increase up to 100 m and more. Quaternary sediments consist mainly of Latvian ice age moraine sediments - moraine loam and sandy loam; fluvioglacial sand deposits or glaciolymnic sand with siltstone and clay deposits are deposited above them. Also, sand-gravel sediments in the form of interlayers up to 5-10 m thick are often found in moraine sediments. Alluvial sediments are found in river valleys, mostly sand is 1-2 m thick, but bog sediments formed by peat are deposited in the relief depressions above the moraine sediments.

Below the Quaternary sediments is the Arukūla-Gauja multi-aquifer system, which includes the Middle Devonian Arukūla and Burtnieki formations sediments, as well as the Upper Devonian Gauja formation sediments (distributed in a small area in the southern part). The complex consists of terrigenous sediments - various degrees of cemented fine to medium-grained sandstones with interlayers of clay and siltstone. In the study area, the thickness of Devonian sediments, which is part of the zone of groundwater active exchange, mainly varies from 48 to 145 m (PUMA Model of the Baltic Artesian Basin results).

The regional aquitard is embedded deeper - the sediments of the Middle Devonian Narva formation: marls and clay sediments with a total thickness mainly of up to 100 m. Throughout the study area, regional aquitard sediments safely separate the zone of groundwater active exchange from the zone of groundwater inactive exchange. Below are situated the sediments of the Upper-Middle Devonian Ķemeri-Pärnu formations sediments, formed by sandstones, siltstones and clay. As well as Ordovician, Silurian, Cambrian and Vendian sediments (Latvian State Geological survey, 2002).

The main type of soils are sod podzolic, swamp peat and sod soils (Fig. 2.1.2).

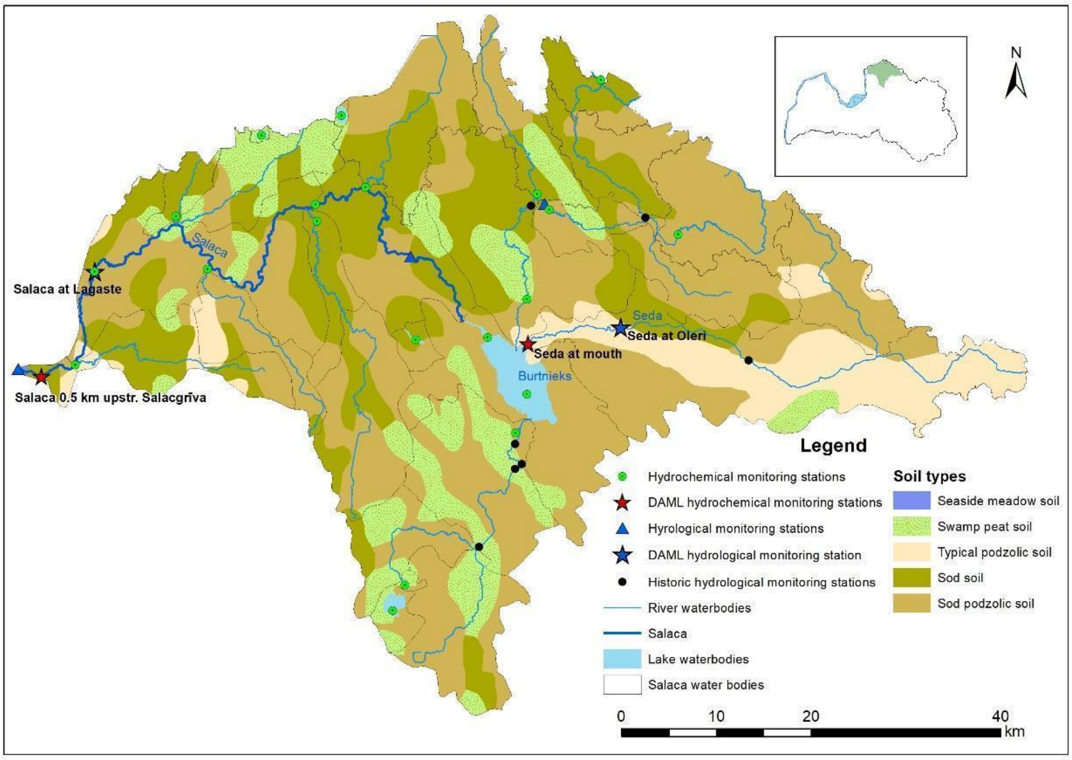


Figure 2.1.2. Soil types in the River Salaca catchment (Envirotech, 2020., LEGMC, 2021).

Climate

The interaction of polar maritime air masses of the North Atlantic origin and polar continental air masses of Siberia have caused frequent changes in cyclonic and anticyclonic activities. In spite of the comparatively small territory, the climatic differences within Salaca River Basin aren't remarkable.

In accordance with data of the climatic norm (1981-2010), the average air temperature changes from +5.9°C on the north-east (Rujiena MS) to +6.3°C on the Riga Gulf coastal area (Ainazi MS).

The average amount of precipitation from the climatic norm is 700 mm in Rujiena and 656 mm in Ainazi.

The average wind speed in Latvia is 3.2 m/s, the strongest wind is usually observed on the Baltic Sea coastal area and in Ainazi, where the annual wind speed reaches 4 m/s.

Observed meteorological data shows a continued positive trend in air temperature (Fig. 2.1.3.) and precipitation data series due to climate change (Fig. 2.1.4.).

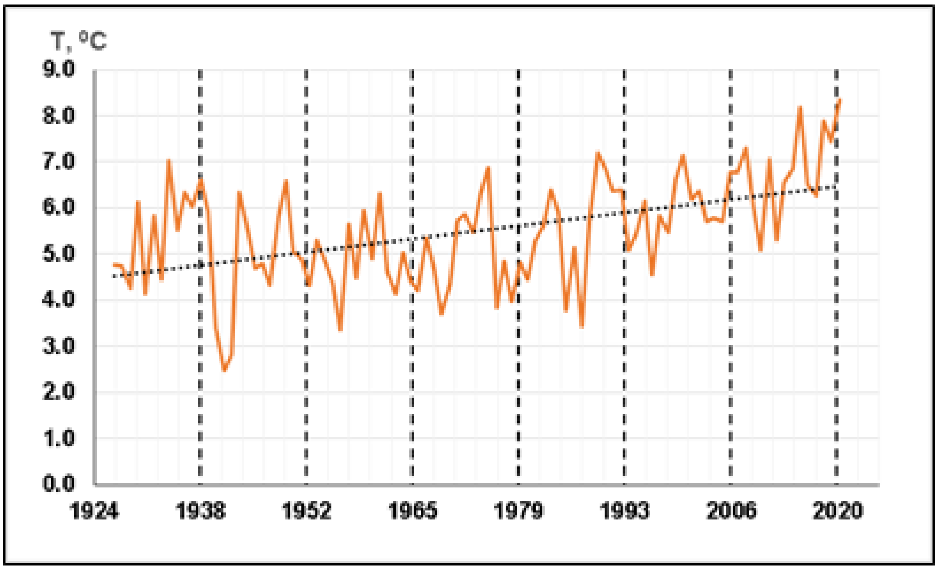


Figure 2.1.3. Yearly data series of the air temperature by Rujiena MS for observation period 1927-2020 (data source: LEGMC).

The climatic norm of the annual air temperature for the period 1981-2010 is 0.7 °C higher than for the reference period 1961-1990.

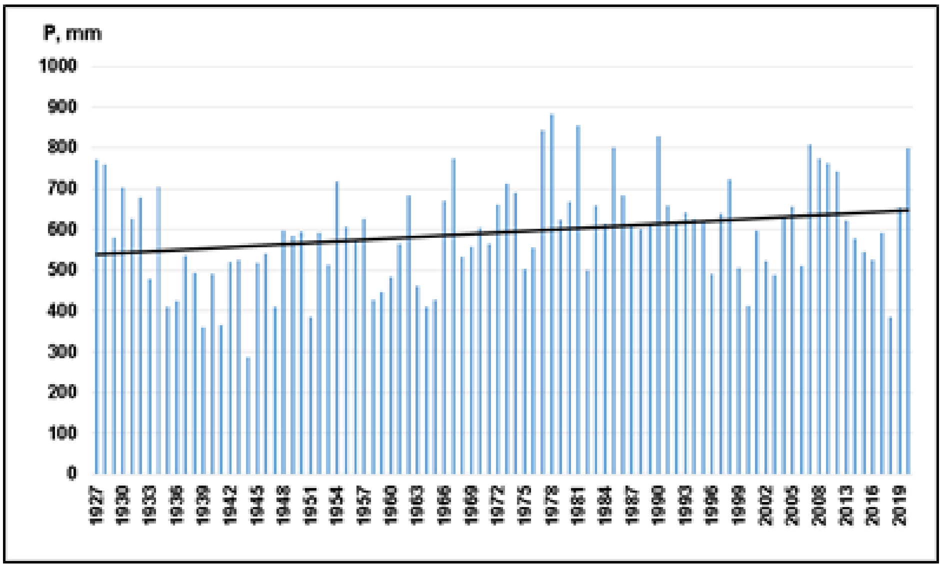


Figure 2.1.4. Yearly data series of precipitation by Ainazi MS for observation period 1927-2020 (data source: LEGMC).

Hydrology

The Salaca/Salatsi jogi River Basin includes 3 rivers flowing into Lake Burtnieki (Ruja /*Ruhja jõgi*, Seda and Briede rivers with their tributaries) and Salaca River that is running out of the Lake with tributaries. Lake Burtnieki is the fourth largest lake in Latvia with a surface area around 40 km^2, volume 0.09 km^3 and the average depth 2.9 m.

The project pilot river, Salaca/Salatsi, is 95 km long and a watershed area 3415 km^2. The average gradient of the river is 0.4 m/km. The main tributaries are: Ramata (from right side, 27 km long, basin area 192 km^2), Ige (from left side, basin area ~ 55 km long, basin area 212 km^2), Jogla (from left side, 32 km long, basin area ~ 77 km^2), Glazupe (from right side, 21 km long, basin area ~ 84 km^2) and Korge (from left side, 31 km long, basin area ~ 109 km^2). The Salaca/Salatsi River Basin has a wide net of amelioration channels. The hydrological regime is regulated by Lake Burtnieki that is smoothing water level fluctuation, decreasing flood peaks and increasing a low flow during a summer season. The annual flow runoff of the Salaca/Salatsi River is 1105 mil. m^3.

The project pilot river, Seda, is 58 km long and a watershed area 575 km^2. River starts from the small marsh nearby Valka/Valga town and flows into Lake Burtnieki. The river average gradient is 0.3 m/km. The main tributary is Rikanda River that is 22.5 km long and has the water area around 107 km^2.Additionaly there are many drainage channels that collect water from swamps within the river basin. The annual flow runoff of the Seda River is 160 mil. m^3.

The water regime of rivers is characterised by the spring flood, winter and summer low flow periods and summer-autumn rain floods. Winter low flow periods are usually interrupted by thaws but summer low flow periods – by rain floods.

The part of a snowmelt in the feeding of Salaca/Salatsi River is 35-40%, groundwater - around 30% and rainfall - 30-35% (Fig.2.1.5.).

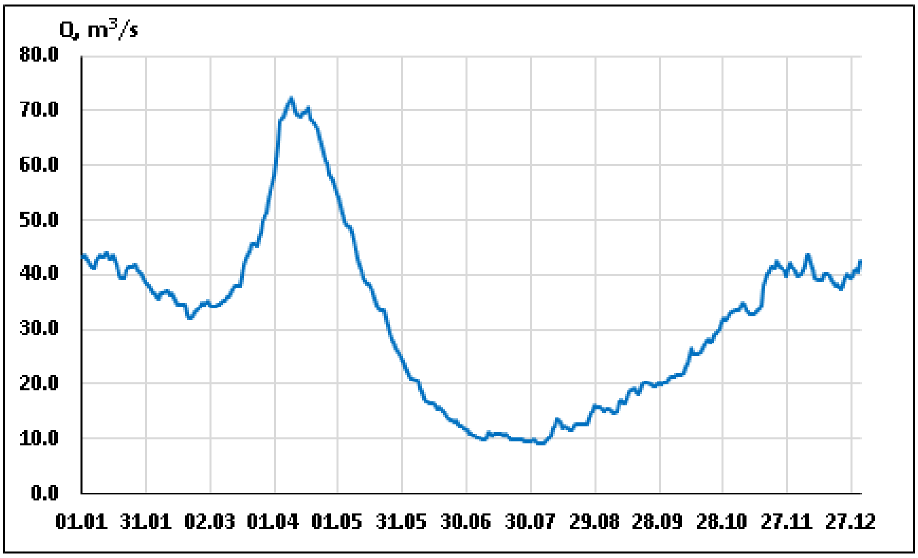


Figure 2.1.5. The hydrograph of Salaca/Salatsi River near Lagaste (data source: LEGMC).

Anthropogenic activities (land use, etc)

Forest land is the dominating land cover type. Forests cover 59% of the Salac catchment and 64% of the Seda River catchment (Fig. 2.1.6. and 2.1.7., Table 2.1.1.). Agricultural land covers about 30% in Salaca and Seda catchments.

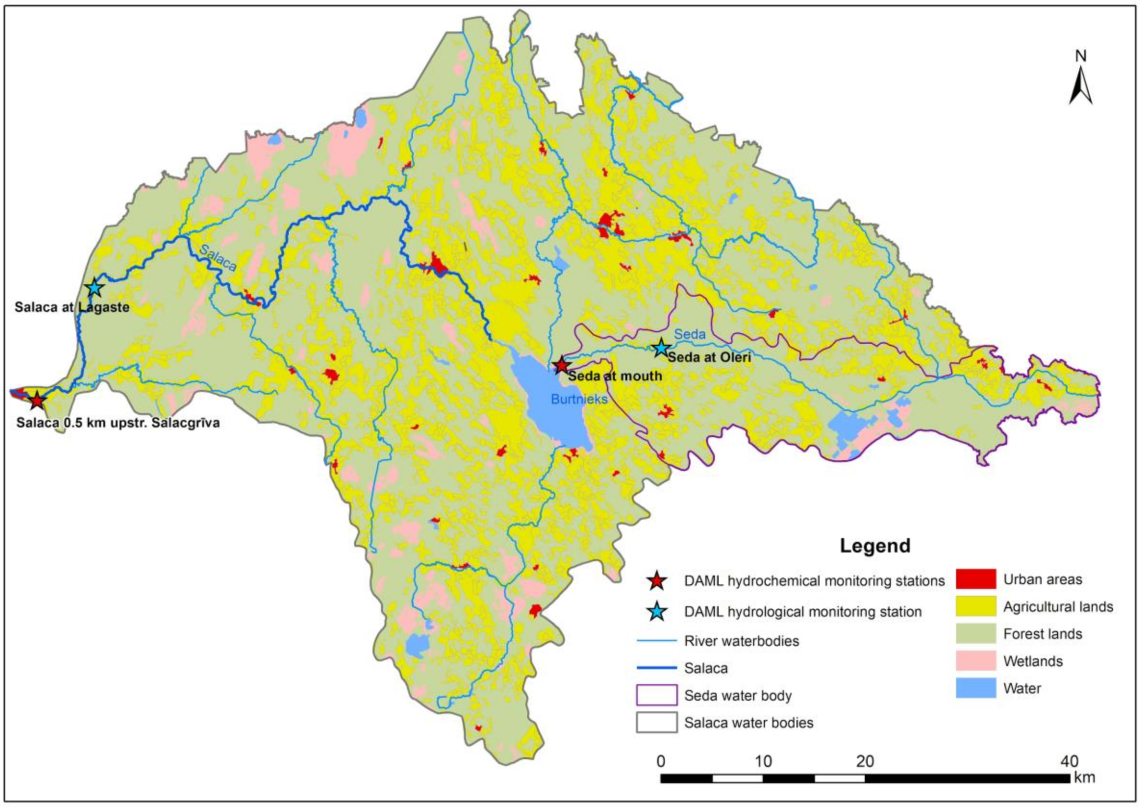


Figure 2.1.6. Land-cover in the Salaca and Seda River basins (CLC, 2018., LEGMC, 2021).

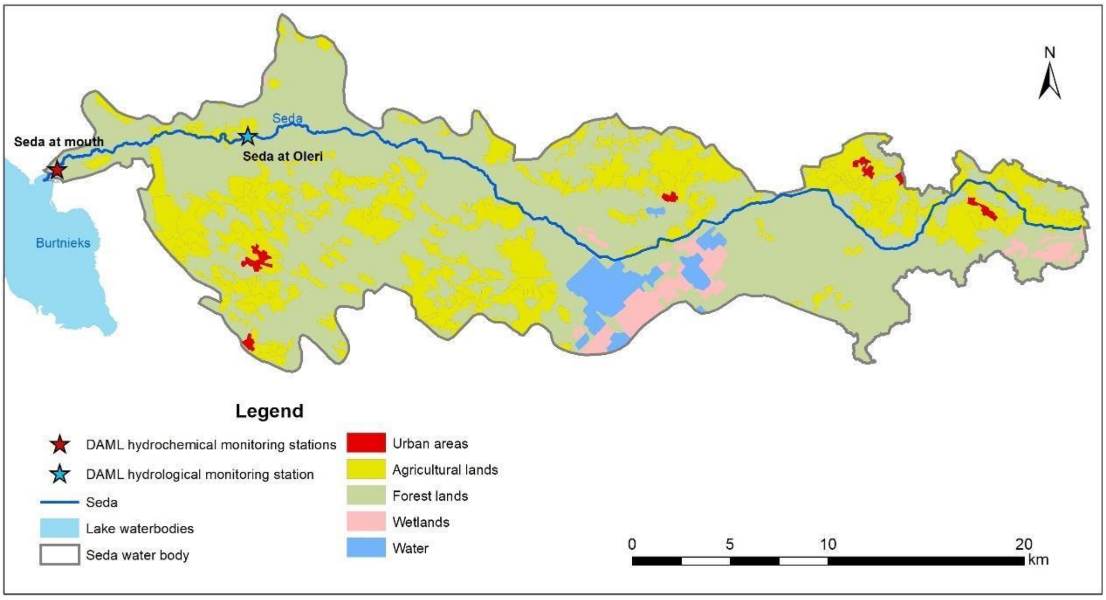


Figure 2.1.7. Land-cover in the Salaca and Seda River basins (CLC, 2018., LEGMC, 2021).

Table 2.1.1.

Major land cover types in the Salaca and Seda catchments (CLC, 2018)

Land use	area, km^2	area, %	area, km^2	area, %
	Salaca		Seda	
Forest areas	1870.97	59%	281.26	64%
Agricultural areas	1075.84	34%	129.81	29%
Wetlands	130.32	4%	14.00	3%
Water	66.11	2%	12.90	3%
Urban areas	23.41	1%	2.91	1%

The largest areas of agricultural land in both Salaca and Seda River catchments are occupied by cereal fields. The second most important category is meadows, pastures and grassland. These land use categories occupy more than 80% of the total agricultural land (Table 2.1.2.).

Table 2.1.2.

Share of agricultural land use categories in the Salaca and Seda River catchments (LAD, 2018).

Land use category	Salaca		Seda	
	area, km^2	% of agricultural land	area, km^2	% of agricultural land
Cereals	344.1	43.6	45.3	48.0
Rapseed	28.8	3.6	5.2	5.5
Flax	0.2	0.03		
Legumes	20.5	2.6	3.2	3.4
Fallow land and bushes	44.2	5.6	6.4	6.8
Meadows, pastures and grassland	334.3	42.4	33.1	35.0
Vegetables	13.7	1.7	0.9	0.96
Permanent crops	3.7	0.47	0.3	0.36

There are 77 wastewater discharge sites in the Salaca river catchment, including Seda river catchment (Fig. 2.1.8.). There are also 177 potentially contaminated sites that might have an impact on water quality as well.

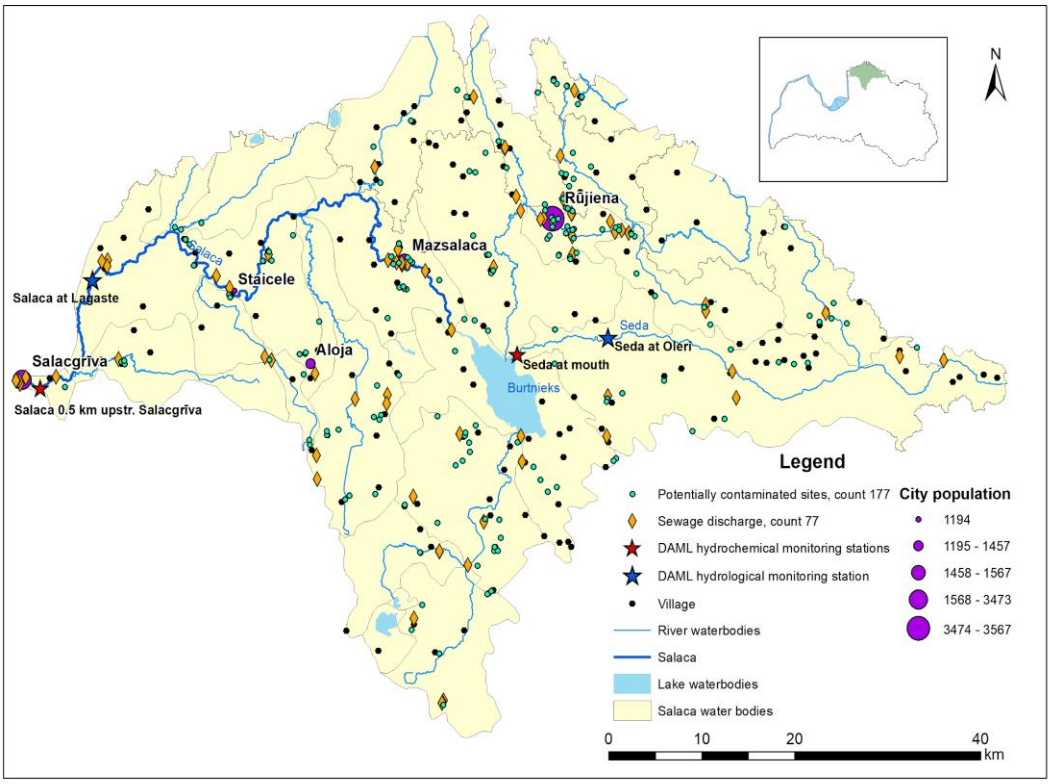


Figure 2.1.8. Location of wastewater discharge sites and potentially contaminated sites (data source: LEGMC).

Around 1000 thousand m^3 of wastewater are released into the environment in the Salaca catchment and about 360 thousand m^3 - in the Seda catchment (Fig. 2.1.9.). Wastewater volume has slightly decreased since the early 2000.

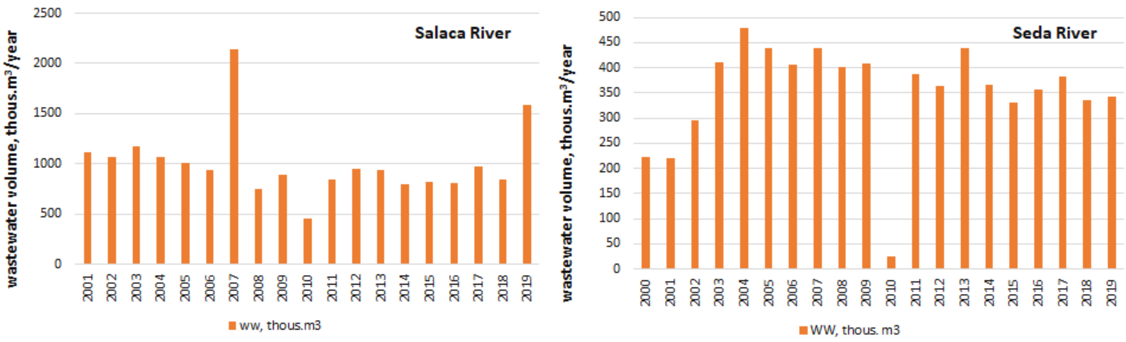


Figure 2.1.9. Volume of wastewater discharged in the Salaca and Seda River catchments (data source: Ūdens-2).

TN load emitted into the environment by wastewater in the Salaca River catchment is about 27 t/year. The load is varying over the last 20 years without any trend (Fig.2.1.10.). The average NNH4 load was about 11.8 t/year during 2000-2019 and it shows a decreasing tendency. During 2014-2019, the average NNH4 load was 9.1 t/year. BOD5 and TP loads have decreased since 2000. During 2014-2019, the average TP load was 4.7 t/year and that of BOD5 was 13.8 t/year (Fig.2.1.10.).

During 2014-2019, about 14.3 tons of TN, 2.0 tons of NNH4, 1.92 t of TP and 2.1 t of BOD5 was emitted annually in the Seda catchment (Fig.2.1.11.).

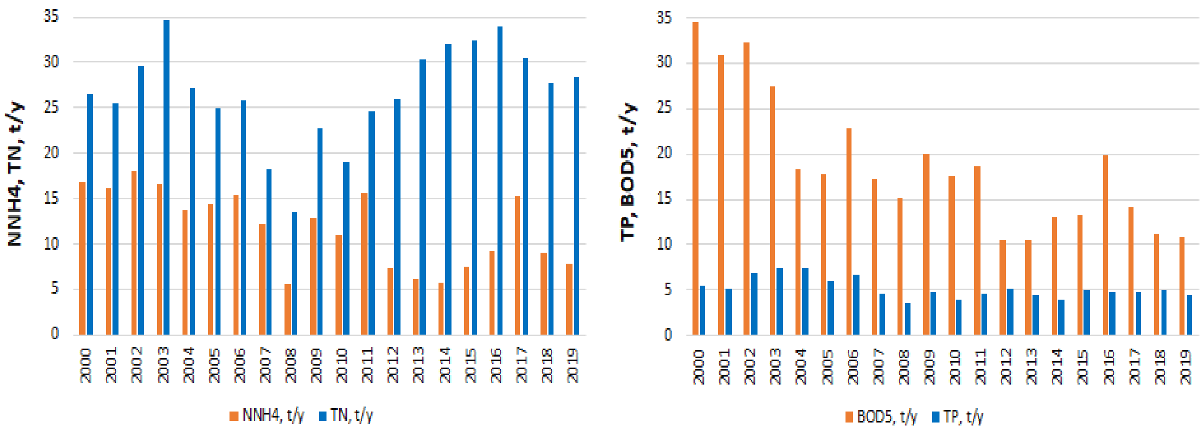


Figure 2.1.10. Changes of nutrient and BOD5 loads discharged by WWTPs located in the Salaca catchment (data source: Ūdens-2).

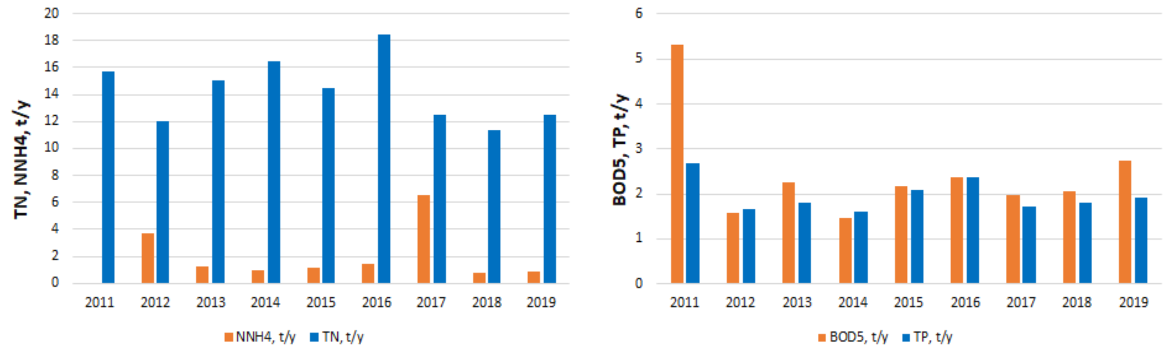


Figure 2.1.11. Changes of nutrient and BOD5 loads discharged by WWTPs located in the Seda catchment (data source: Ūdens-2).

2.2. Physico-geographical description of the Pärnu river catchment

The Pärnu river drains into the Pärnu Bay. The length of the river is 144 km and it´s catchment area is 6920 km^2 (Table 2.2.1). Its sources are in the upland of Pandivere including the river Vodja (Figure 2.2.1), where water rich springs on the slope of the Pandivere upland feed the upstream part of the rivers. Other tributaries include the rivers Navesti and Halliste that join the Pärnu river from the upland of Sakala and the rivers Reiu and Sauga that join the river Pärnu in the downstream part of the catchment.

Table 2.2.1.

Total catchment area of the studied rivers.

	River	Catchment area, km^2
2; 6	Pärnu, incl.	6920
1	Vodja	79.7
3	Tahkuse	2069
4	Navesti	3004
5	Halliste	1891
7	Reiu	906
8	Sauga	577

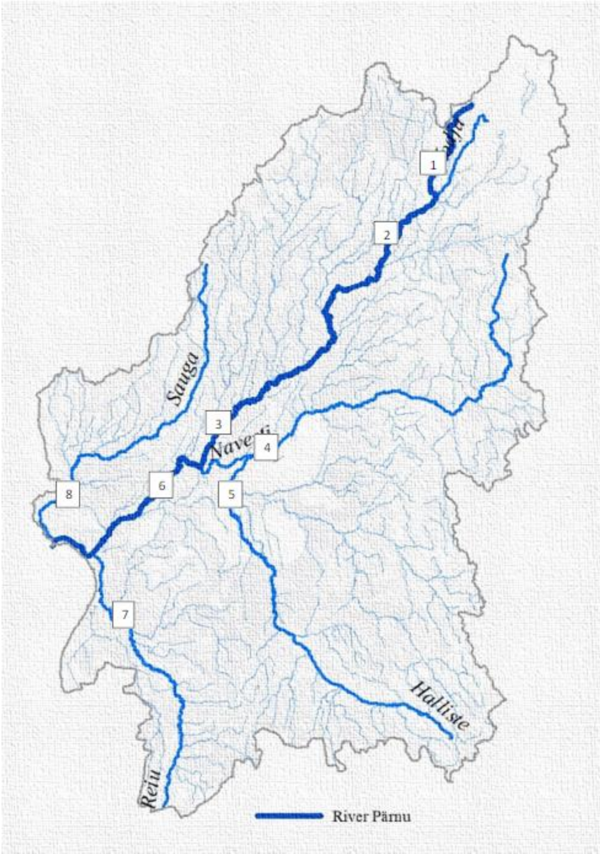


Figure 2.2.1. Studied rivers in the Pärnu river catchment area and location of hydrochemistry monitoring sites (numbers in table 1).

Geology and geomorphology

The sedimentary cover of the crystalline basement of the river Pärnu watershed consists of Lower Silurian limestones and dolostones and Middle Devonian sandstones and claystones (Figure 2.2.2.). The limestones–dolomites (green) with widely spread karst phenomena is prevail in the upstream and northern part of the catchment and sandstone, aleurite and clay (green) in the South (Figure 2.2.2.). The layers of the sedimentary cover are tilted southwards. These geological features largely determine the formation of groundwater quality as well as the type of the running waters, its color and the content of humic substances and nutrients. The thickness of the quaternary sediments, e.g., moraine, that cover the sedimentary rock vary from 5 to 60 m, while they can only be 1 m thick in some locations. The varved clay deposits laying on the moraine is the main reason for lower infiltration of water. This has also resulted in a quite remarkable share of peaty soils and peatlands in some parts of the river catchment (Figure 2.2.3.).

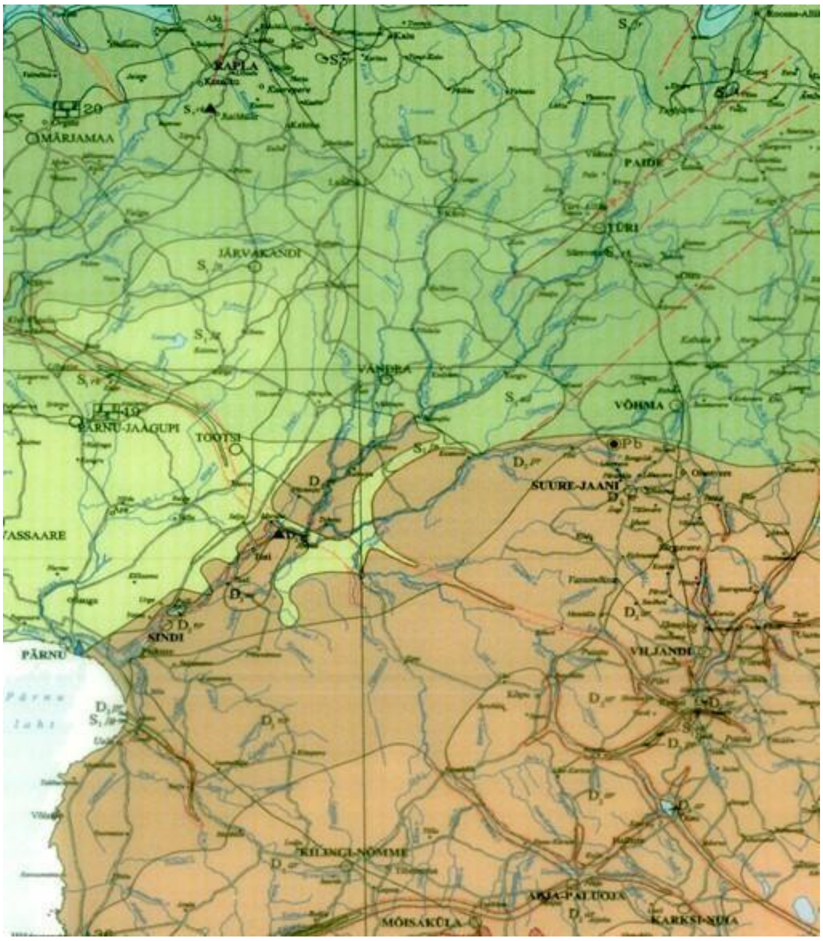


Figure 2.2.2. Geological map of the study area (Geological Survey of Estonia).

The drainage area of the river Pärnu is relatively flat by topography. The absolute altitude in the downstream part of the river is 0-50 m, increasing slowly towards inland, where it reaches nearly 80 meters (Figure 2.2.3).

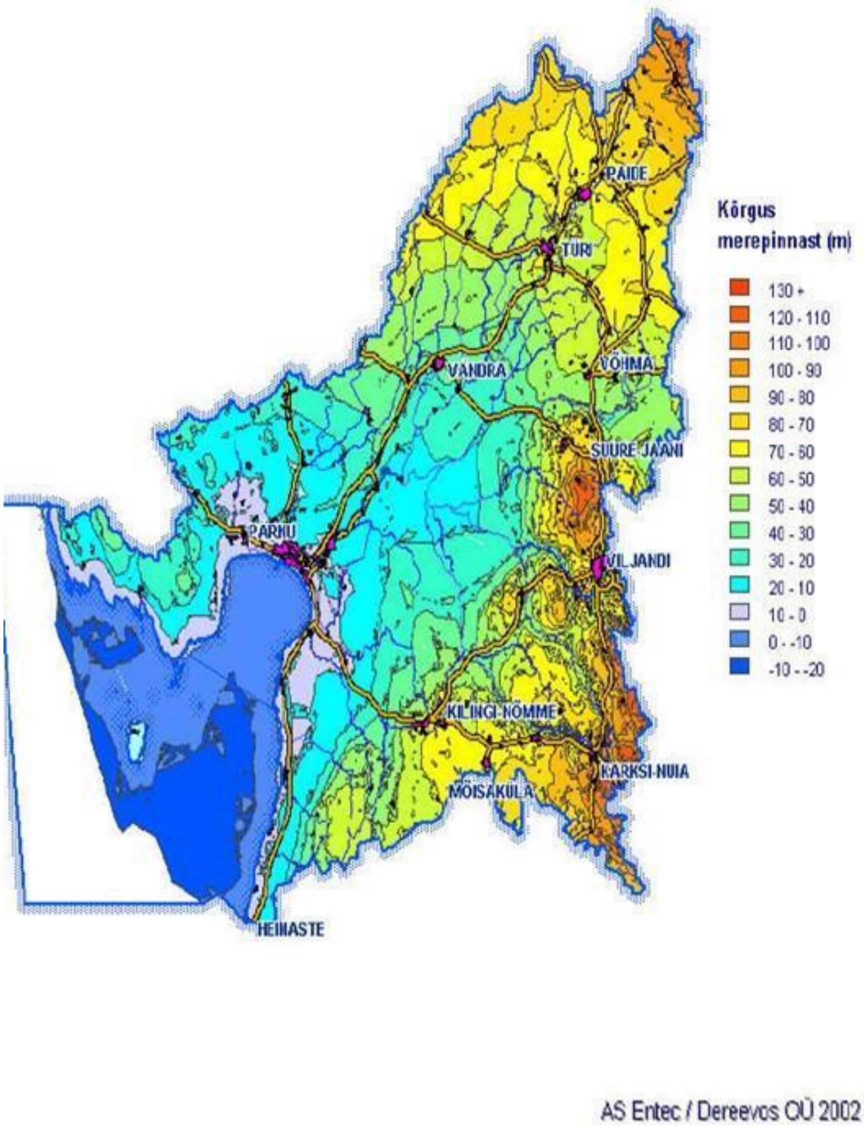


Figure 2.2.3. Topography of the River Pärnu catchment area (Extracted from: AS Entec, 2002)

The dominating soils in the uspstream part of the Pärnu river are Cambisols while Podzols, Gelyic Cambisols and Luvisols. Peaty gleysols and open lawn and pool communities are quite common in the middle and downstream part of the catchment (Figure 2.2.4.).

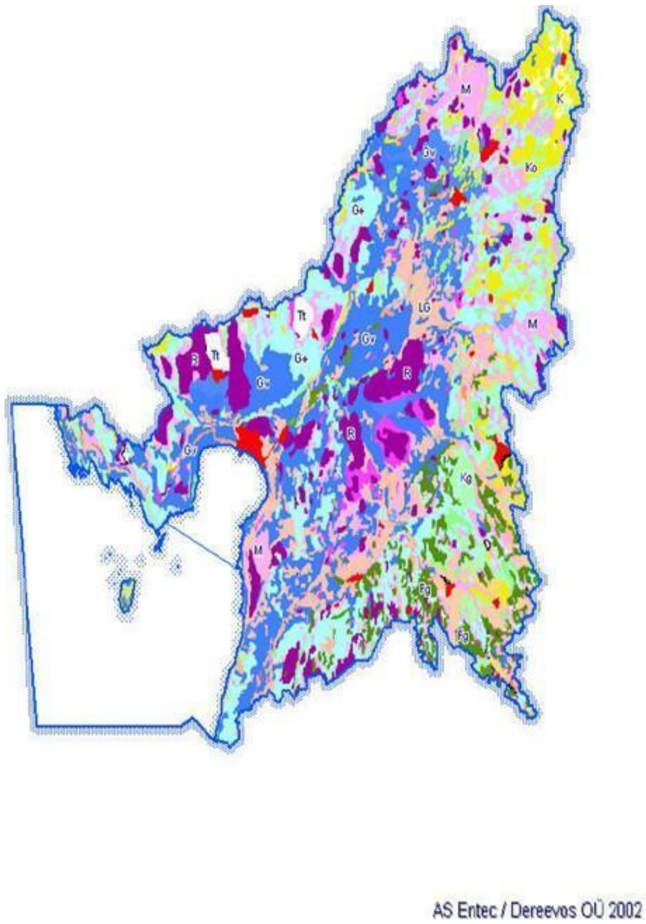


Figure 2.2.4. Soil map of the river Pärnu catchment area (Extracted from: AS Entec, 2002).

Climate

Mean annual temperature in meteorological stations within or near the river Pärnu catchment varies from 6.0 - 6.2 °C in the inland stations Türi and Viljandi to 6.8 °C in the Pärnu station in 1991-2020. Lower temperatures at the Türi and Viljandi stations compared to the Pärnu station are particularly pronounced during winter months (Table 2.2.1.).

Mean long-term annual precipitation during the same period ranged from 726 to 761 mm (Table 2.2.1.). About 310-340 mm of precipitation feeds the water bodies considering the mean annual evapotranspiration in the watershed that is about 420 mm.

Table 2.2.1

Mean annual temperature and precipitation in meteorological stations in 1991-2020 (Data: Estonian Weather Service).

Meteorological station	Mean temperature, °C	Precipitation, mm
Pärnu	6.8	761
Türi	6.0	726
Viljandi	6.2	747

Table 2.2.2.

Mean monthly air temperature (°C) in 1991-2020 (Data Estonian Weather Service).

Meteorological station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Pärnu	-3.0	-3.7	-0.5	5.4	11.4	15.4	18.3	17.2	12.5	6.8	2.2	-0.9	**6.8**
Türi	-3.9	-4.5	-0.9	5.2	11.0	15.1	17.8	16.2	11.4	5.7	1.2	-1.9	**6.0**
Viljandi	-4.0	-4.4	-0.7	5.6	11.4	15.3	17.9	16.5	11.7	5.9	1.2	-2.0	**6.2**

Precipitation data does not show any statistically significant increasing or decreasing trends during two studied periods in 1993-2019 and 2009-2019 (Table 4).

Table 2.2.3.

Trends in monthly sum of precipitation in meteorological stations within or near the Pärnu river catchment (Data: Estonian Weather Service).

Meteorological station	1993-2019		2009-2019	
	MK-Stat	p-value	MK-Stat	p-value
Pärnu	-0.11	0.457	0.10	0.460
Türi	0.14	0.444	-1.09	0.139
Viljandi	0.10	0.459	-	-

One-sided test, statistically significant if p<0,05

Hydrology

The long-term annual mean flow of the River Pärnu at the downstream hydrological station Oore based on the data by Estonian Weather Service is 49.5 m^3/s, while varying from 2.5 to 810 m^3/s, indicating a large annual and seasonal variation in runoff. The specific runoff is 9.6 $l/s/km^2$ varying in other studied streams from 8.7 at the Naveti/Aesoo station to 12.8 $l/s/km^2$ at the Reiu/Laadi station (Table 2.2.4.).

Table 2.2.4.

Long-term mean flow in hydrological stations (data: Estonian Weather Service).

River/station	Catchment area, km^2	Distance from river mouth, km	Mean flow, m^3/s	Minimum flow, m^3/s	Maximum flow, m^3/s	Specific runoff, $l/s/km^2$
Pärnu/Türi-Alliku	579	108	5.27	0.78	36.5	9.1
Pärnu/Tahkuse	2080	41.1	19.9	0.86	412	9.6
Pärnu/Oore	5160	15.7	49.5	2.48	810	9.6
Navesti/Aesoo	1030	13.9	9.0	0,20	169	8.7
Halliste/Riisa	1880	5.5	17.3	0.23	250	9.2

Reiu/Laadi	556	13.9	7.1	0.14	104	12.8
Sauga/Nurme	546	10.4	6.1	0.054	95	11.1
Vodja/Vodja	52	7.7	0.5	0.04	4.9	8.8

The share of groundwater recharge in river water varies a lot being considerably higher in streams whose source is in the Pandivere upland (e.g., the rivers Vodja and Esna), where it forms more than 50% of the discharge. The share of groundwater recharge in river water in the downstream tributaries of the river Pärnu, the rivers Reiu, Hallitse and Navesti, is only 16%, 25% and 28%, respectively (Järvekülg, 2001). The mean daily Base Flow Index (BFI) of the river Vodja in 1993-2019 is 0.77, varying from 0.66 to 0.87 during the studied years, while being high also in the Esna River - 0.78 (0.64-0.88) (Table 6). Rather low daily mean BFI is typical for the rivers Sauga at the Nurme station and Reiu at the Laadi station in 2007-2019, where it is only 0.45 and 0.46, respectively. The BFI describes the proportion of the river runoff from stored sources (Gustard et al., 1992) like groundwater, wetlands, etc. The high BFI levels indicate the importance of groundwater recharge in the Vodja river, as well as high share of wetlands in the watershed, particularly in the river Esna. The BFI of the lowland rivers Navesti and Halliste is 0.57 and 0.59, respectively.

Table 2.2.5.

Long-term (1993-2019 or 2007-2019) mean daily base flow index (BFI) for the studied rivers.

River/station	BFI, mean for 1993-2019
Vodja-Vodja	0.77 (0.66 -0.87)
Esna-Põhjaka I	0.78 (0.64-0.88)
Navesti-Aesoo	0.57 (0.41-0.70)
Halliste-Riisa	0.59 (0.43-0.73)
Pärnu-Tahkuse	0.63 (0.45-0.78)
Pärnu-Oore	0.61 (0.51-0.75)
Sauga-Nurme (2007-2019)	0.45 (0.33-0.52)
Reiu-Laadi (2007-2019)	0.46(0.35-0.54)

Anthropogenic activities

The share of agricultural land area in studied catchments according to the CORINE Land Cover classes vary from 19% in the Reiu-Lähkma station to 59% in the River Vodja catchment (Table 2.2.6., Figures 2.2.5. – 2.2.8.). The Reiu and Sauga river catchments have the largest share of forests and wetlands, 80% and 68% respectively, while it is only 41% in the river Vodja catchment. The share of artificial surfaces is 1.7% in the Pärnu-Tahkuse catchment and 1.5% in the Pärnu-Oore and Halliste-Riisa catchments. The catchment of the river Reiu has only 0.7% of artificial surfaces.

Tabel 2.2.6.

Major CORINE land cover types in the river catchments upstream the water quality monitoring stations.

River/station	Type	Catchment area, km^2	Agricultural land (%)	Forest (%)	Wetland (%)	Artificial (%)	Water (%)
Pärnu-Oore	3B	5154	36	58	5	1.5	0.1
Pärnu-Tahkuse	2B	2069	38	56	4	1.7	< 0.1
Sauga-Nurme	2A	545	31	56	12	0.9	0.2
Reiu-Lähkma	2A	531	19	78	2	0.7	< 0.1
Navesti-Aesoo	3B	1041	36	58	5	1.1	< 0.1
Halliste-Riisa	3A	1873	34	60	4	1.5	0.3
Vodja-Vodja	1B	51	59	36	5	1.2	< 0.1

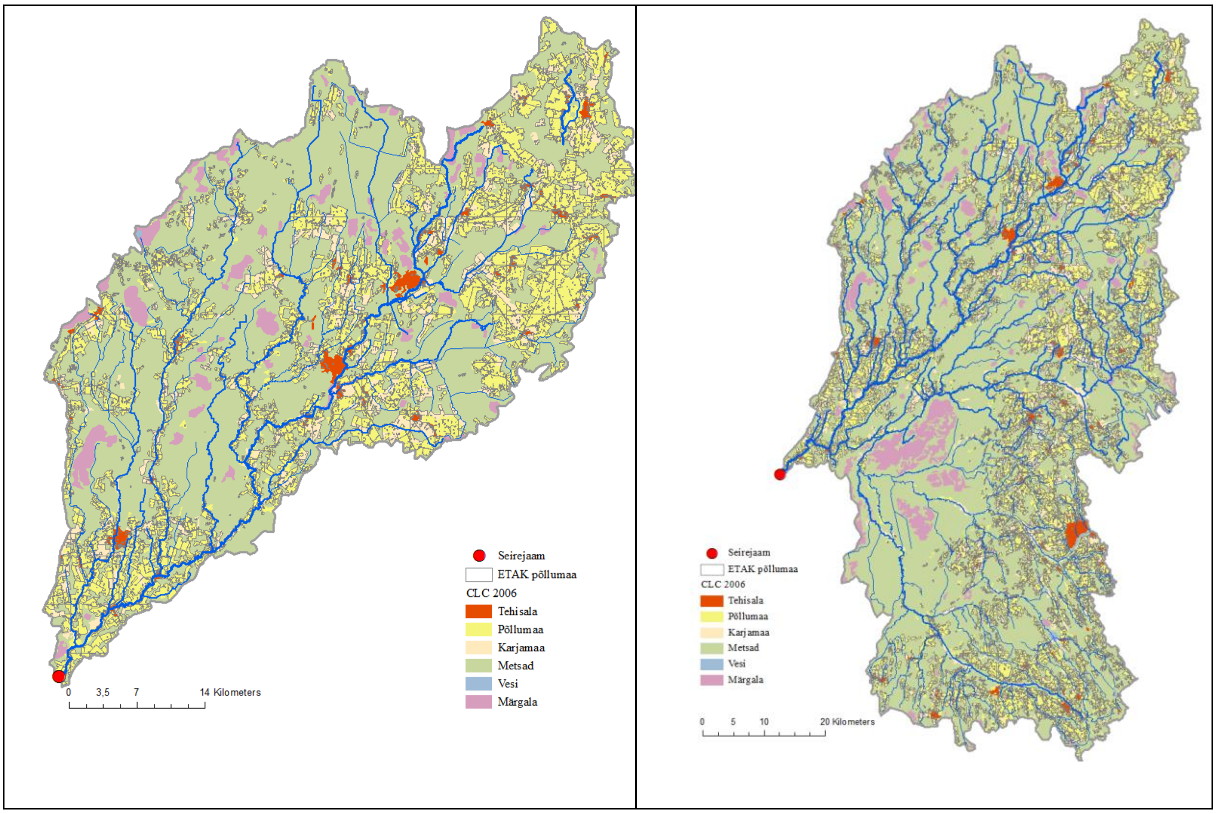


Figure 2.2.5. CORINE land cover in Pärnu –Tahkuse (left) and Pärnu-Oore (right) catchments (extracted from: Thalfeldt, 2013).

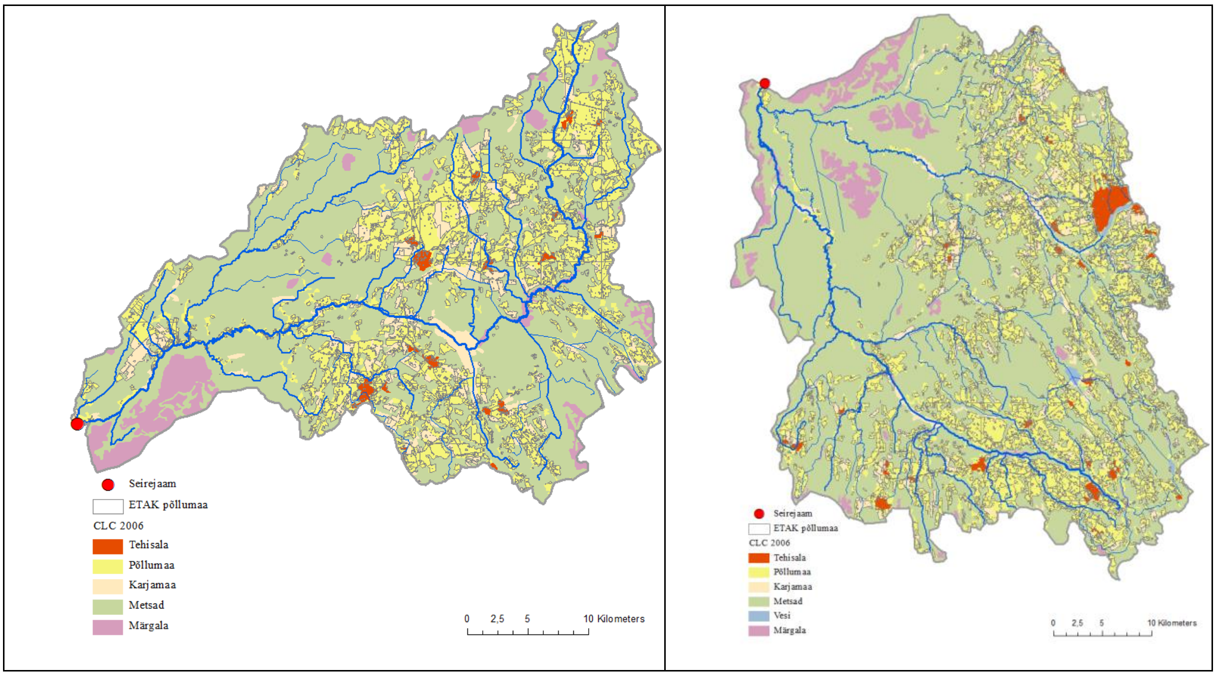


Figure 2.2.6. CORINE land cover in the Navesti-Aesoo (left) and Halliste-Riisa (right) catchments (extracted from: Thalfeldt, 2013).

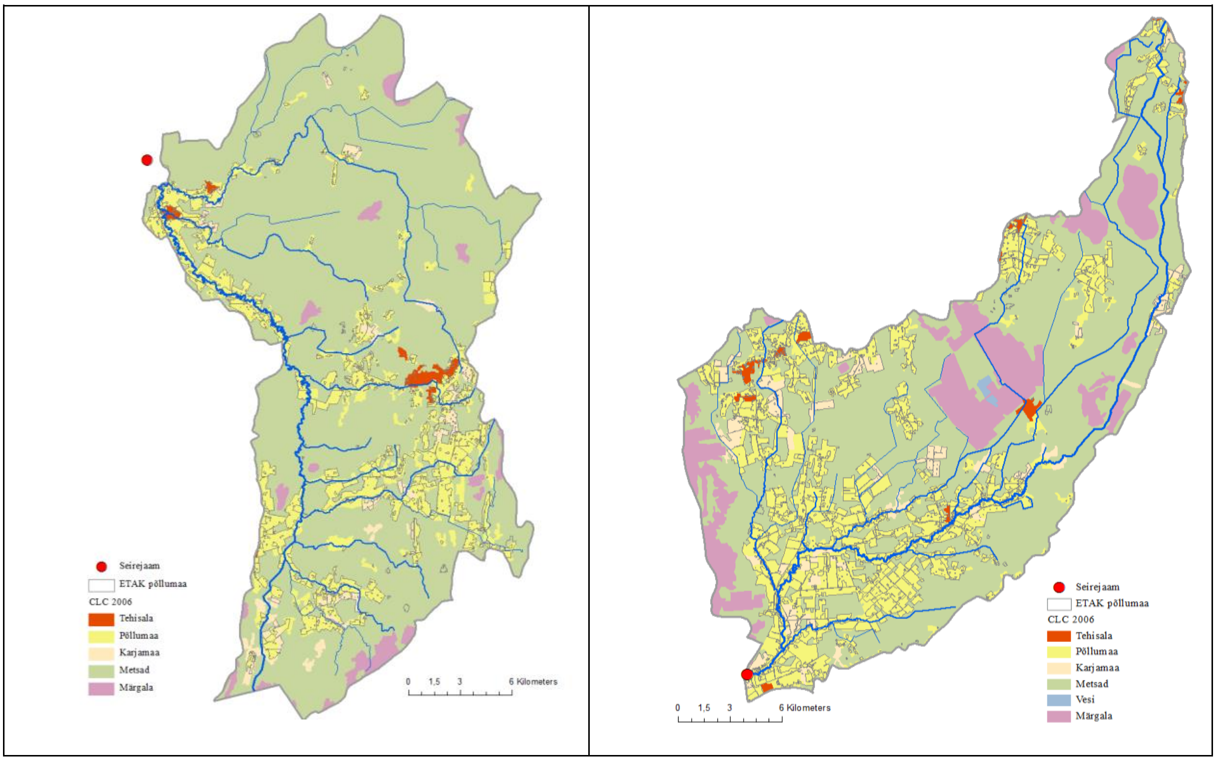


Figure 2.2.7. CORINE land cover in the Reiu-Lähkma (left) and Sauga-Nurme (right) catchments (extracted from: Thalfeldt, 2013).

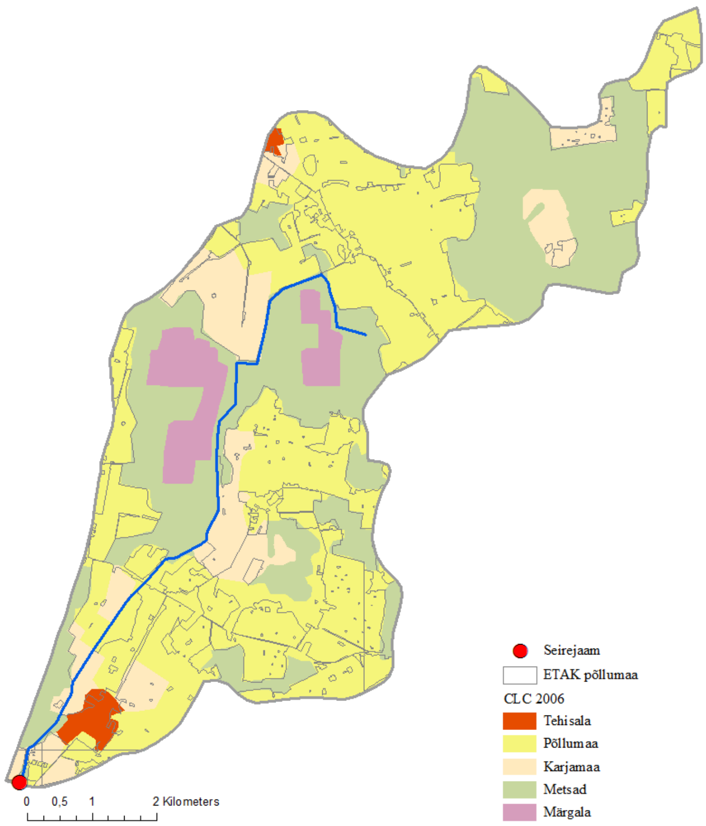


Figure 2.2.8. CORINE land cover in the Vodja catchment (extracted from: Thalfeldt, 2013).

Table 2.2.6. provides agricultural land-use data for three counties in the river Pärnu catchment area in 2019 and 2020 (Data: Statistics Estonia). Only major land-use categories are involved. The area under cereals and industrial crops is relatively larger in Viljandi (44% and 10% of the used agricultural land area, respectively) and Järva counties (41% and 10%), while it is only 29% and 4% in Pärnu county. The share of permanent grasslands in Pärnu county is relatively larger, occupying 39% of agricultural land, while the share is only 16% and 19% in Järva and Viljandi counties, respectively.

Table 2.2.7.

Major agricultural land-use categories in Järva, Pärnu and Viljandi counties in 2019 and 2020 (Data: Statistics Estonia).

County	Land-use, ha	2019	2020	% of used agricultural land area
Järva	Used agricultural land	81399	80877	
	Arable land	67783	67786	
	Cereals	31991	33491	41%
	Legumes	3191	4200	5%
	Industrial crops	7517	7844	10%
	Forage crops	19652	18710	23%
	Permanent grassland	13529	12997	16%
Pärnu	Used agricultural land	103060	103257	
	Arable land	62554	62412	
	Cereals	29241	30299	29%
	Legumes	3976	4561	4%
	Industrial crops	4356	3897	4%
	Forage crops	22701	21701	21%
	Permanent grassland	40161	40533	39%
Viljandi	Used agricultural land	86428	86249	
	Arable land	68869	69406	
	Cereals	37917	38295	44%
	Legumes	5339	5922	7%
	Industrial crops	8572	8404	10%
	Forage crops	15274	15139	18%
	Permanent grassland	17071	16373	19%

The Statistics Estonia provide data about the number of livestock by counties. The number of livestock units (LU) in three counties of the Pärnu river catchment in 2020 varies from 10,660 in Järva county to 42,431 in Viljandi county (Table 2.2.8.). The total number of cattle in three counties showed decreasing trend in early 2000s following the overall economic situation in Estonia, but it has been increasing during the last decade (Figure 2.2.9.).

Table 2.2.8.

Number of livestock units (LU) in three counties in 2020 (Data: Statistics Estonia).

County	LU	LU/km^2 of agricultural land area
Järva county	10,660	0.13
Pärnu county	28,451	0,28
Viljandi county	42,431	0,49

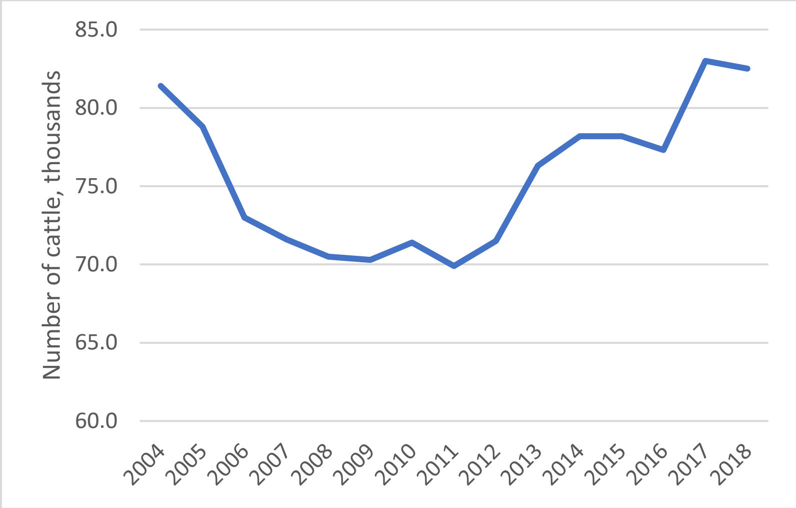


Figure 2.2.9. Number of cattle in three counties in 2004-2018.

The use of organic fertilizers follows to some extent the trend in the size of cattle population in Järva, Pärnu and Viljandi counties (Figure 2.2.10.).

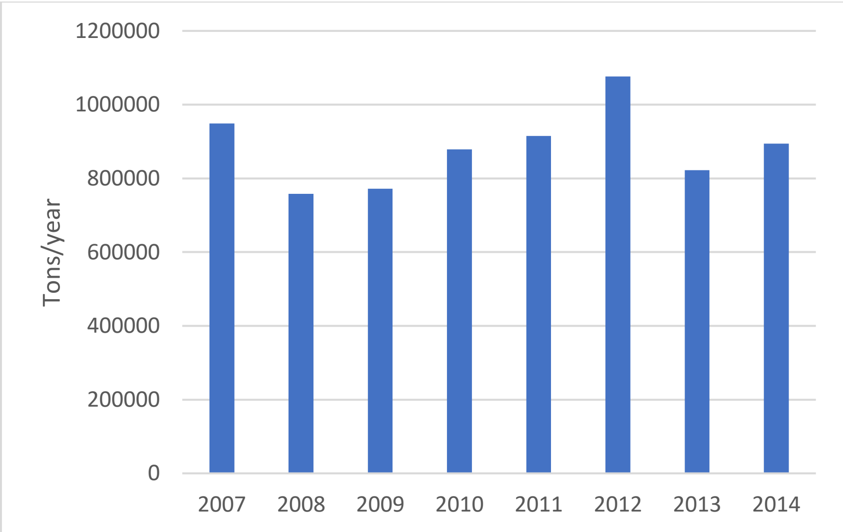


Figure 2.2.10. Use of organic fertilizers in Järva, Pärnu and Viljandi counties in 2007-2014 (Data: Statistics Estonia).

3. Data sources and methods

● 3.1. Hydrological and hydrochemical data

Hydrological and hydrochemical monitoring in Latvia is carried out by the Latvian Environment, Geology and Meteorology Center (LEGMC). The location of all hydrological and hydrochemical monitoring stations in the River Salaca basin is shown on Figure 3.1.1.

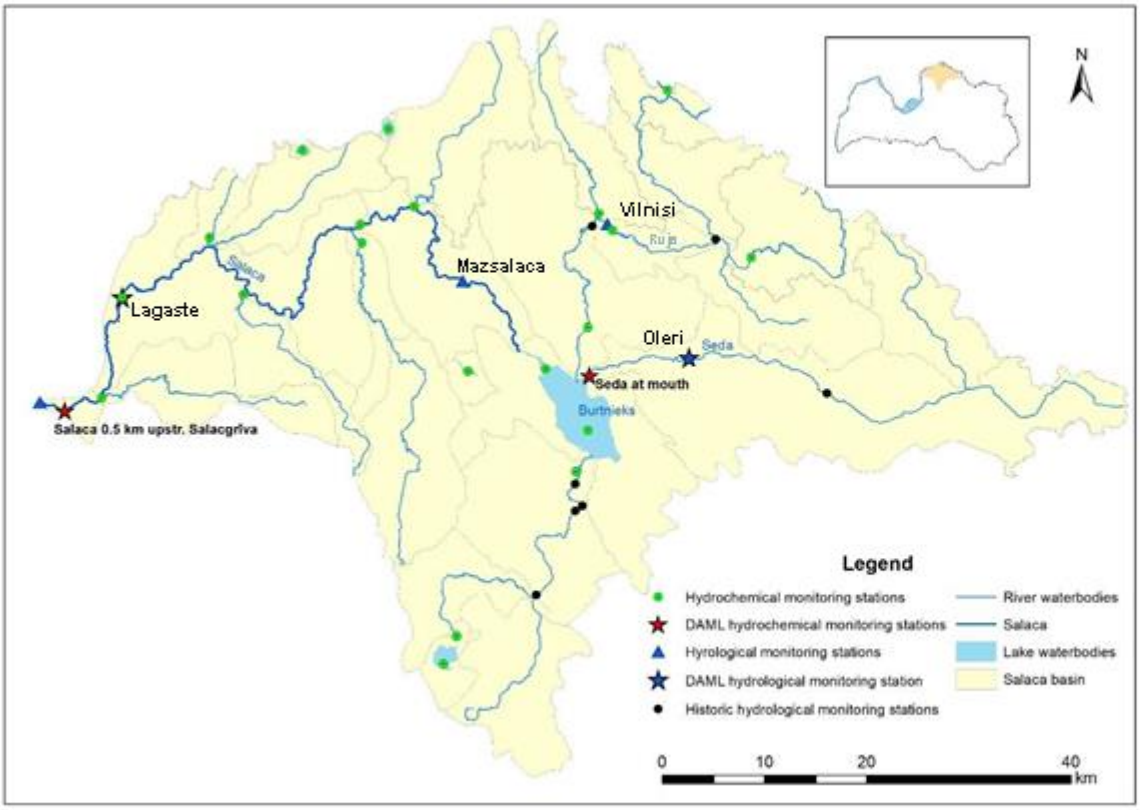


Figure 3.1.1. Location of hydrological and hydrochemical monitoring stations in the River Salaca catchment (LEGMC, 2021).

The hydrological data availability is shown in Table 3.1.1.

Table. 3.1.1.

Hydrological data series of rivers within Salaca/Salatsi River Basin

River/Lake-Station	Distance from mouth, km	Basin area, km^2	Water level data	Flow data
Salaca-Mazsalaca	83	2260	1930-1943, 1951-2019	1951-2019
Salaca-Lagaste	20	3220	1930-2019	1927-1943, 1946-2019
Seda-Oleri	12	431	1979-2019	1979-2019

Ruja-Vilnisi	23	636	1978-2019	1978-2019
Lake Burtnieki - Burtnieki		2215	1967-2008, 2012-2019	

During the analysis of observed flow data the inhomogeneity of data series have been defined. Different activities related to creating the wide drainage system within the territory of the Salaca/Salatsi River Basin that started in 1960ies, caused this data inhomogeneity. Therefor in this project flow data series of Lagaste hydrological station from the observation period 1961-2019 was used. Flow data series of Oleri station is used for the whole observation period.

After the examination of available data, it was decided to apply the DAML methodology to analyze water quality exceedances at hydrochemical stations River Salaca, 0.5 km upstream Salacgrīva and River Seda at the river mouth. Other stations have been monitored less frequently and have only few measurements (Table 3.1.2).

Loads at the monitoring station River Salaca 0,5 km upstream Salacgrīva represent the total load from the Salaca river catchment. It is the most frequently monitored station in the whole Salaca catchment. The data from the station are used to calculate and report loads for HELCOM needs.

Table 3.1.2.

Sampling period and number of samples at the two hydrochemical monitoring stations.

Parameter	**R.Salaca 0.5km upstr. Salacgrīva**	**R.Seda at mouth**
Total nitrogen (TN)	1993 – 2019 (n = 262)	2007 – 2016 (n = 16)
Total phosphorus (TP)	2004 – 2019 (n = 141)	2007 – 2016 (n = 16)
Biochemical oxygen demand (BOD5)	1990 – 2019 (n = 221)	2007 – 2016 (n = 16)
Ammonium nitrogen (NNH_4^+)	1990 – 2019 (n = 305)	2007 – 2016 (n = 16)

Data on daily discharges for period 1961 – 2019 are available for the hydrological station River Salaca at Lagaste. A coefficient 1.082 was applied to extrapolate the discharge estimated at the hydrological station to the hydrochemical station. Data on daily discharges for period 1978 – 2019 are available for the hydrological station River Seda at Oleri. A coefficient 1.334 was applied to extrapolate the discharge to the hydrochemical station River Seda at mouth.

Daily flow and monthly runoff data in hydrological stations in 1993-2019 (2007-2019 for the rivers Reiu and Sauga), as well as the mean annual temperature and precipitation data in meteorological stations in 1991-2020 has been provided by the Estonian Weather Service at the Estonian Environmental Agency. Monthly or bi-monthly hydrochemical data collected within the national environmental monitoring program has also been provided by the Environmental Agency.

- **3.2. Data sources on anthropogenic pressures**

Data on discharged wastewater volume, TN, TP, NNH4 and BOD emissions from point sources are available from the national statistics database "2-Ūdens".

Latvian Geospatial Information Agency (LĢIA) provides data of elevation information about Latvia. Date of year for different regions differs, but data used in Salaca basin has been acquired in 2019. Data are raw XYZ type that are being prepared for further use by ourselves as we see them in Physical map of Salaca river basin.

Information about soil has been acquired from geodatabase called GIS Latvija 10.2 that has been provided by other GIS organization in Latvia – SIA "Envirotech".

Land cover information has been published in year 2018. Main provider is Copernicus that provides Corine Land Cover information available for all Europe. Information includes different artificial surfaces, agricultural areas, forest and seminatural areas, wetlands and water bodies. More detailed information about agricultural areas in 2018 has been provided by LAD (Rural Support Service Republic of Latvia).

Thalfeldt (2013) provide data on the share of CORINE land cover types in studied catchments of Estonia. Unfortunately, more recent data about some major agricultural pressures is available only on the county level, including agricultural land-use, the number of livestock, annual use of mineral and organic fertilizers.

The point source data for the rivers Reiu and Sauga of annual load of nutrients, BOD_7 and suspended solids to the rivers from different sources, as well as the direct discharges to the Baltic Sea were obtained from the National Water Use Database (VEKA) at the Estonian Environmental Agency.

- **3.3. Calculation of daily allowable maximal loads (DAML)**

The DAML is the maximum amount of cumulative load of pollutants (kg/tons/day) from different sources acceptable for the specific river without exceeding quality standards and the buffering capacity of the stream, or for achieving water management targets. The methodology is based on the application of the flow duration curve and the streamflow exceedance probability curve (EPA, 1991 and 2007).

First, the flow exceedance probability curve is developed. Flow duration curves serve as the foundation for development of load duration curves, on which DAMLs can be based. A load duration curve is developed by multiplying stream flow with the numeric water quality target (usually a maximum allowable concentration) and a conversion factor for the pollutant of concern. Observed concentrations at the hydrochemical monitoring stations are multiplied by measured discharge value at the sampling date and a conversion factor to obtain observed daily load. The observed daily load then is compared to DAML at a given discharge rate.

To develop the load duration curves for the studied rivers in Salaca catchment, boundary values of good/moderate and high/good ecological quality classes were used (Table 3.3.1.). There are six river types in Latvia: 1: small, rhithral rivers; 2: small potamal rivers; 3: medium-size rhithral rivers, 4: medium-size potamal rivers; 5: large, rhithral rivers; 6: large, potamal rivers. Load duration curves were developed for daily allowable maximum loads of TN, TP, N/NH_4^+, and BOD_5. River Salaca 0.5 km upstream Salacgrīva belongs to a river type 6 which is a large potamal river. River Seda at mouth belongs to a river type 4, which is a medium-size potamal river.

Table 3.3.1.

Ecological quality classes according to physico-chemical parameters

Type	Parameter	Unit	High	Good	Moderate	Bad	Poor
1	O_2	mg/l O_2	>8	6.0 - 8.0	4.0 - 6.0	2.0 - 4.0	<2
	BOD_5	mg/l O_2	<2.0	2.0 – 2.5	2.5 – 3.0	3.0 – 3.5	>3.5
	N/NH_4	mg/l N	0.09	0.09 - 0.12	0.12 – 0.15	0.15 – 0.18	>0.18
	TN	mg/l N	<1.5	1.5 - 2.0	2.0 – 2.5	2.5 – 3.0	>3.0
	TP	mg/l P	<0.04	0.04 – 0.065	0.065 – 0.090	0.090 – 0.115	>0.115
2	O_2	mg/l O_2	>7	5.0 - 7.0	3.0 - 5.0	1.0 - 3.0	<1
	BOD_5	mg/l O_2	<2.0	2.0 – 3.0	3.0 – 4.0	4.0 – 5.0	>5.0
	N/NH_4	mg/l N	<0.1	0.1 - 0.16	0.16 – 0.24	0.24 – 0.32	>0.32
	TN	mg/l N	<1.5	1.5 – 2.5	2.5 – 3.5	3.5 – 4.5	>4.5
	TP	mg/l P	<0.045	0.045– 0.090	0.090 – 0.135	0.135 – 0.180	>0.180
3	O_2	mg/l O_2	>8	6.0 - 8.0	4.0 - 6.0	2.0 - 4.0	<2
	BOD_5	mg/l O_2	<2.0	2.0 – 2.5	2.5 – 3.0	3.0 – 3.5	>3.5
	N/NH_4	mg/l N	<0.09	0.09 - 0.12	0.12 – 0.15	0.15 – 0.18	>0.18
	TN	mg/l N	<1.8	1.8 - 2.3	2.3 – 2.8	2.8 – 3.3	>3.3
	TP	mg/l P	<0.05	0.05 – 0.075	0.075 – 0.100	0.100 – 0.125	>0.125
4	O_2	mg/l O_2	>7	7.0 - 5.0	3.0 - 5.0	3.0 - 1.0	<1
	BOD_5	mg/l O_2	<2.0	2.0 – 3.0	3.0 – 4.0	4.0 – 5.0	>5.0
	N/NH_4	mg/l N	<0.16	0.16 – 0.24	0.24 – 0.32	0.32-0.40	>0.40
	TN	mg/l N	<2	2.0 – 3.0	3.0 – 4.0	4.0 – 5.0	>5.0
	TP	mg/l P	<0.06	0.06 – 0.090	0.090 – 0.135	0.135 – 0.180	>0.180
5	O_2	mg/l O_2	>8	6.0 - 8.0	4.0 - 6.0	2.0 - 4.0	<2
	BOD_5	mg/l O_2	<2.0	2.0 – 2.5	2.5 – 3.0	3.0 – 3.5	>3.5
	N/NH_4	mg/l N	0.09	0.09 - 0.12	0.12 – 0.15	0.15 – 0.18	>0.18
	TN	mg/l N	1.8	1.8 - 2.8	2.8 - 3.8	3.8 - 4.8	>4.8
	TP	mg/l P	<0.04	0.04 – 0.065	0.065 – 0.090	0.090 – 0.115	>0.115
6	O_2	mg/l O_2	>7	5.0 - 7.0	3.0 - 5.0	1.0 - 3.0	<1

	BOD_5	mg/l O_2	<2.0	2.0 – 3.0	3.0 – 4.0	4.0 – 5.0	>5.0
	N/NH_4	mg/l N	<0.1	0.1 - 0.16	0.16 – 0.24	0.24 – 0.32	>0.32
	TN	mg/l N	<1.8	1.8 – 2.8	2.8 – 3.8	3.8 – 4.8	>4.8
	TP	mg/l P	<0.045	0.045–0.090	0.090 – 0.135	0.135 – 0.180	>0.180

Maximum allowed concentrations (water quality target) of N_{tot} and P_{tot} for the streams in the Pärnu river catchment are defined as <3.0 mg and <1.5 N/l for nitrogen and <0.08 and <0.05 mgP/l for phosphorus as maximum annual mean concentrations for the streams with the catchment area less than 10,000 km^2 (Keskkonnaministri 24.04.2020. a määrus nr. 19).

Thus, it will be possible to calculate the percentage of time (days) that each concentration/load is equalled or exceeded the flow duration (load) curve value as:

$$P(\%) = (m / n+1) * 100, \text{ where}$$

P = the probability that a given flow will be equaled or exceeded (% of time)
m = the ranked position on the listing

n = the number of events for period of record

Loads above the curve indicate an exceedance of the water quality criterion, while those below the load duration curve show compliance.

Loads with the exceedance probablity (P) 0-10% indicate high flow period while the exceedance probablity between 10-40% reflect moist to wet period and more saturated soil conditions with prevailing anaerobic biodegradation and transport of degradation compounds to rivers. The exceedance probability between 40-60% is a transition zone between moist and wet conditions and the flow exceedance probability between 60-80 %, reflect dry period and aerobic conditions in soils. Loads with the exceedance frequency 80 to 100% are characteristic for the low flow periods, likely permanent input from point sources, insufficient handling of wastewater, poor dilution with natural water, etc.

More straight line of the exceedance probability curve in the middle zones indicates less extreme flows and regulated water flow while unregulated system has larger variability of flow. Detailed description of DAML methodology is to be found in the Report of the Activity T.1.1 DAML methodology.

- **3.4. Statistical methods**

Average and median values were calculated for the data rows of discharge and concentrations. Percentiles (25th, 75th) which characterizes the data spread around the mean value as well as standard deviation were calculated.

Sen's slope estimator was calculated for discharge, TN, TP, N/NH_4^+, BOD5 data rows to assess long-term changes (units/year). Sen's slope was estimated using the NGMP Calculator Spreadsheet developed by Daughney (2010). The multivariate Mann-Kendall test (as described by Hirsch and Slack, 1984) for monotone trends in time series of data was chosen for the determination of trends, as it can be applied to rows with a non-normal data distribution and it is a relatively robust method concerning missing data. Partial Mann-Kendall test was used to assess the human impact on the concentrations of nutrients and BOD5 under the influence of natural fluctuations, e.g., water discharge). The Mann-Kendall test was applied separately to each variable. A trend was considered as statistically significant at the 95% confidence level if the test statistics was greater than 1.65 or less than -1.65. The MULTIMK/PARTMK program was used for trend analysis (Libiseller and Grimvall, 2002).

For Pärnu river basin A Mann-Kendall (MK) test (Libseller and Grimvall, 2002) and a modified version of the seasonal Mann-Kendall test, referred to as the partial Mann-Kendall test (PMK), to account for the influence of cofounding variables (i.e. water discharge) has been applied for trend analysis of nutrients and BOD content and load.

- **3.5. Nutrient source apportionment methods**

For nutrient source apportionment modeling in Salaca river basin *FyrisNP* tool was used. The dynamic *FyrisNP* model calculates source apportioned gross and net transport of nitrogen and phosphorus in rivers and lakes. The time step for the model is in the majority of applications one month and the spatial resolution is on the sub-catchment level. Retention, i. e. losses of nutrients in rivers and lakes through sedimentation, up-take by plants and denitrification, is calculated as a function of water temperature, nutrients concentrations, water flow, lake surface area and stream surface area. The model is calibrated against a time series of measured nitrogen or phosphorus concentrations by adjusting two parameters (Hansson et al. 2008).

Data used for calibrating and running the model can be divided into time dependent data, e. g. time series on observed nitrogen and phosphorus concentration, water temperature, runoff and point source discharges, and time independent data, e. g. land-use information, lake area and stream length and width (Hansson et al. 2008).

In order to perform simulations with the FyrisNP model, an *Excel* file containing all input data is required. The Excel data file consists of eight to ten different worksheets depending on features used. It must contain data describing sub-catchments, such as land use, stream lengths and lake areas etc., water temperature, N_{tot} and P_{tot} concentrations in runoff from different land use types, observed P_{tot} or N_{tot} concentrations, minor point sources and major point sources of nutrients (Hansson et al. 2008).

Once the *Exce*l file is uploaded the data is automatically assigned to the sub-catchments. The model determines the number of monitoring stations. Calibration is performed automatically, starting with the Monte Carlo method completed with manual calibration. When the calibration is complete it is possible to view the results - observed and simulated nutrient concentrations. Nutrient loads are calculated by month. In the result section of the model the incoming and the outgoing load in sub-catchment and the source apportionment from various land use types, minor or major point sources are available. The results are available for download as an *Excel* file and can be used for further analysis and graphic depiction (Hansson et al. 2008).

4. Variability of river discharge and nutrient runoff

- **4.1. Seasonal variability of Salaca river basin**

Discharge of Salaca and Seda rivers have pronounced seasonal changes (Figs. 4.1.1. and 4.1.2.). The highest median and maximum discharges are observed in April during the snowmelt. About half of the annual river discharge in Latvian rivers occurs in spring. Summer low-water minimum starts in June and continues until early September. However, during intense rainfall, discharge can increase to levels comparable to spring discharges.

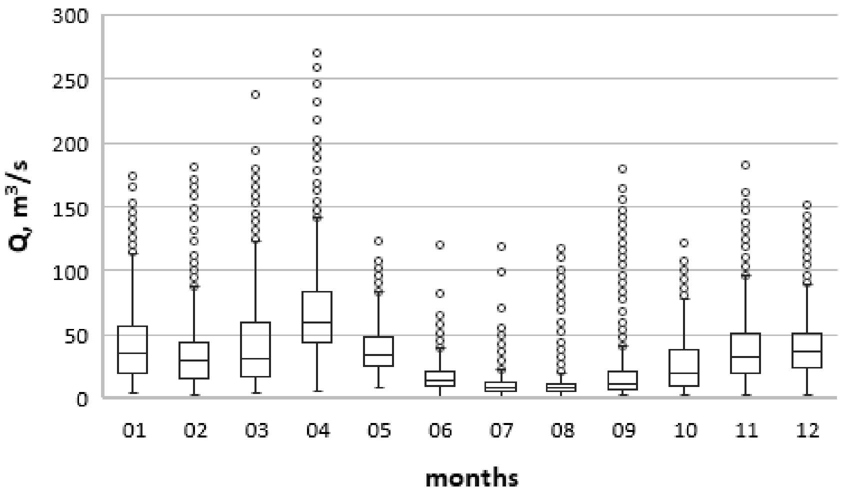


Figure 4.1.1. Seasonal changes of river discharge in Salaca at hydrological station Lagaste (1961-2019).

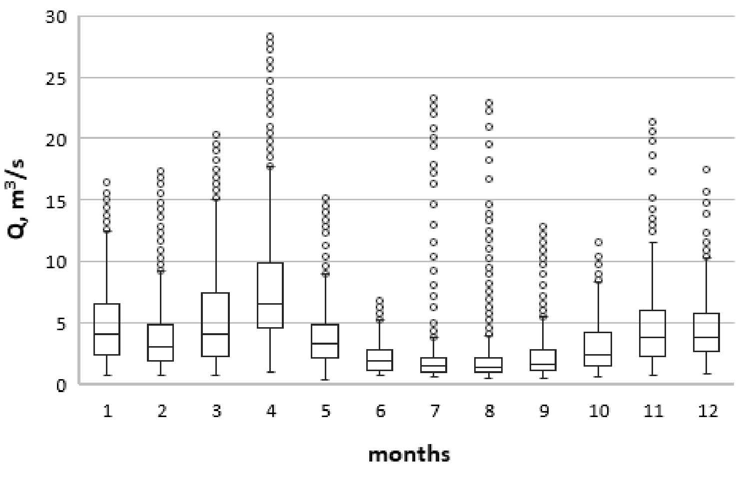


Figure 4.1.2. Seasonal changes of river discharge in Seda at hydrological station Oleri (1978-2019).

Concentrations of chemical parameters also show seasonal variability (Figs. 4.1.3. and 4.1.4.). The seasonal changes in concentrations of nutrients and organic matter largely depend on agricultural intensity and inputs from point sources and therefore they have greater seasonal fluctuations than parameters depending only on natural processes (Kļaviņš et al., 2001). Seasonal pattern of concentration of nitrogen compounds is similar to seasonal changes of discharge. The highest concentrations of N are observed in spring during maximum discharge when nutrients are washed out from soils. The highest monthly average concentration of TN in Salaca is observed in April (2.38±0.80 mg/L), but the highest monthly average concentration of N/NH_4^+ (0.06 mg/L) - February and March. The lowest N concentrations in surface waters are recorded in summer, when N are intensively consumed by living organisms, but inflow of N from catchment by runoff is minimal. The lowest monthly average concentration of TN (0.98±0.25 mg/L) is observed in July. The lowest monthly average concentration of N/NH_4^+ (0.038-0.039 mg/L) is observed in May, July and September. Concentrations of TP and BOD5 show a different seasonal pattern. The highest monthly average concentration of TP (0.070±0.023 mg/L) is observed in August, but the lowest (0.038±0.011 mg/L) - in April. The highest monthly average concentration of BOD5 (2.22±1.54 mg/L) is also observed in August, but the lowest (1.07±0.31 mg/L) - in February. Inputs from point sources probably are responsible for higher concentrations in low-water periods.

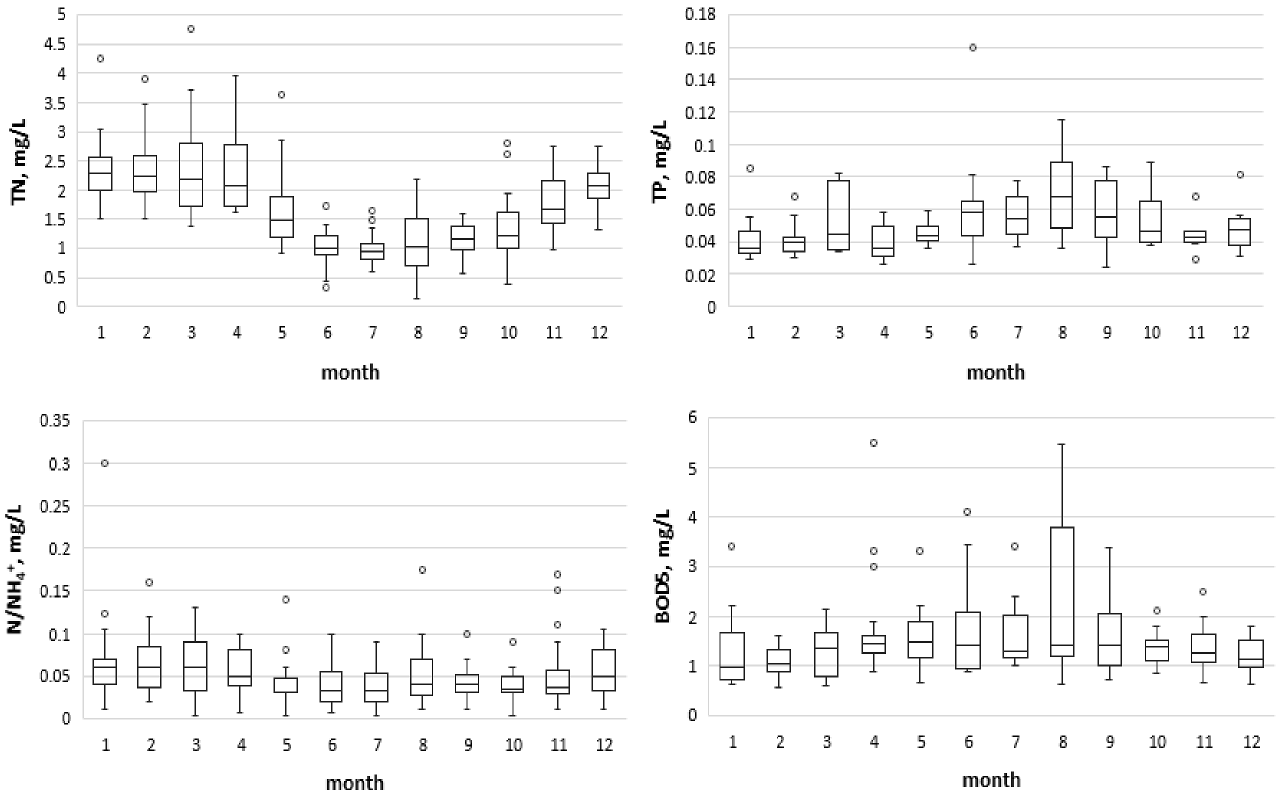


Figure 4.1.3. Seasonal changes of nutrient and BOD5 concentration in Salaca river upstream Salacgrīva.

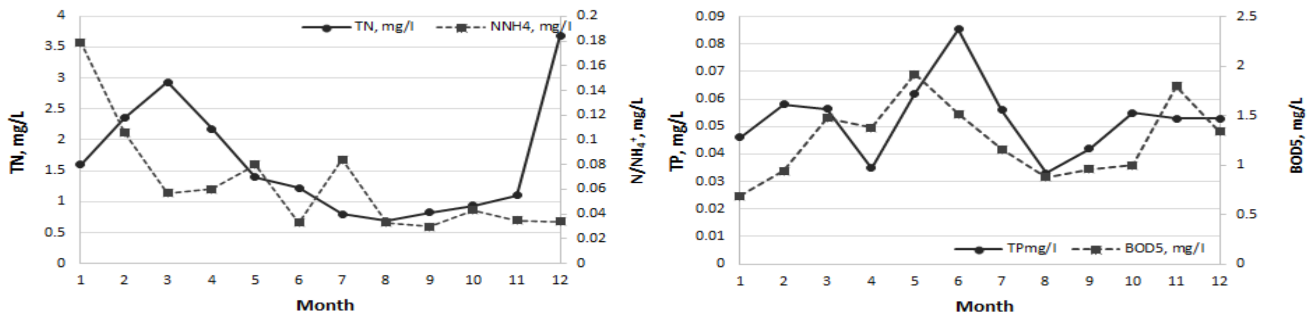


Figure 4.1.4. Seasonal changes of nutrient and BOD5 concentration in Seda River at mouth.

Monthly sampling covers well all hydrological phases (Fig 4.1.5.)

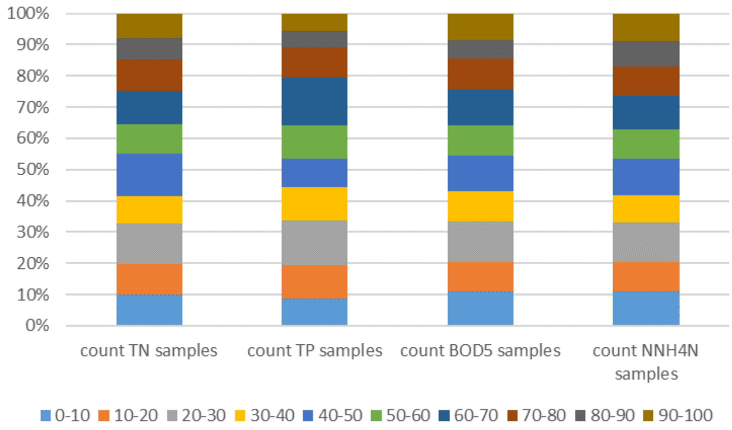


Figure 4.1.5. Distribution of sampling across different flow-regimes (color scale represents probability exceedances (P, 0-100%) at interval 10%.

- **4.2. Seasonal variability of Pärnu river basin**

Monthly discharge in river stations show pronounced seasonal variation (Figure 4.2.1.). The flow maximum in all rivers is in April. Low flow is typical during summer, particularly in June-July.

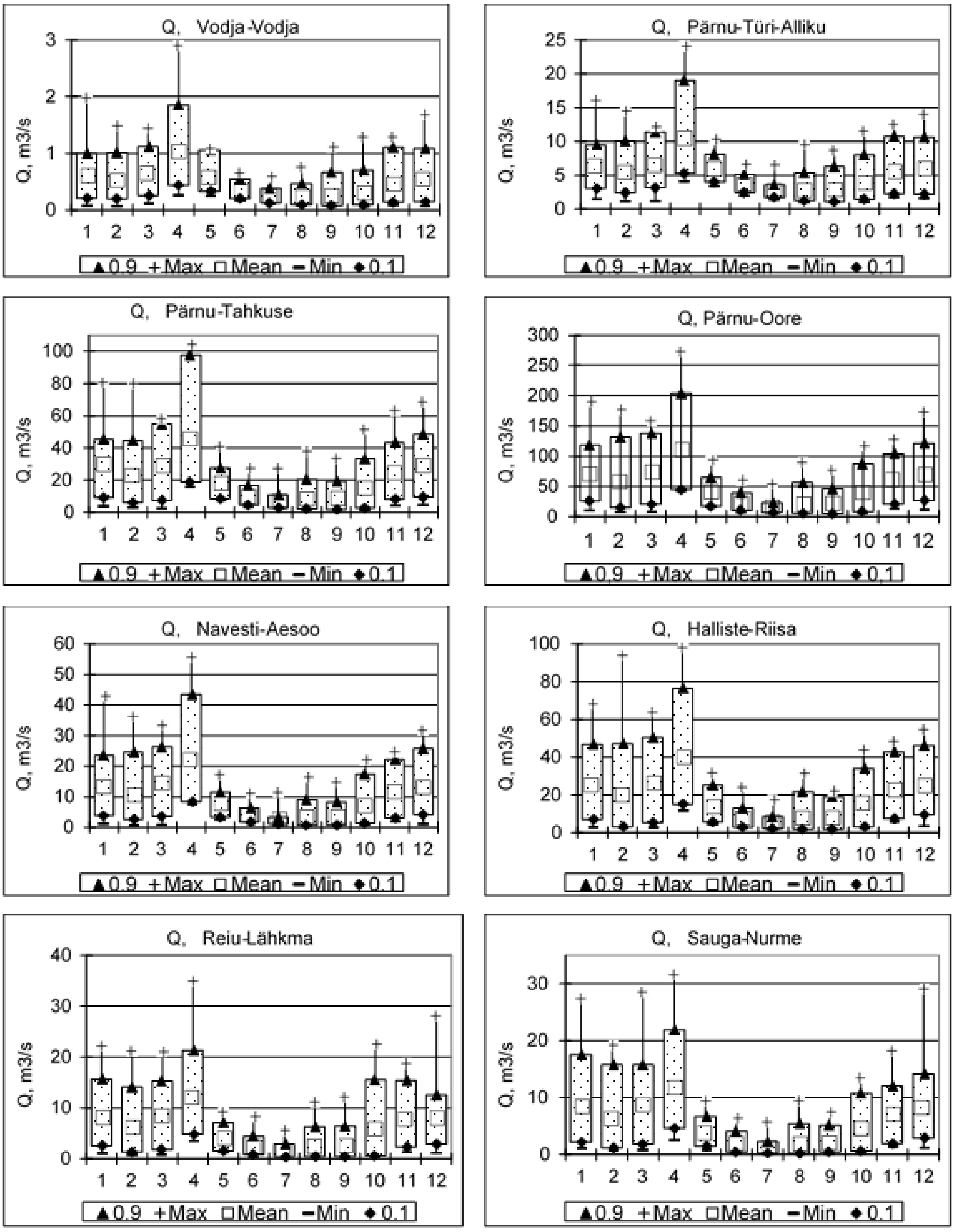


Figure 4.2.1. Monthly discharge in the river stations in January-December 1993-2019

Mean monthly sum of precipitation in Pärnu, Türi and Viljandi stations during summer time 1993-2020 varies from 70.7 to 93.7 mm (Table….). The trend analysis revealed statistically significant decreasing trend in precipitation in December in Viljandi station and less significant decrease in Pärnu and Türi stations.

Table 4.2.1.

Sum of the mean monthly precipitation (mm) in Pärnu, Türi and Viljandi stations during summer in 1993-2020 (Data: Estonian Weather Service).

Station	June	July	August
Pärnu	85.5	78.3	78.1
Türi	79.9	70.7	93.7
Viljandi	84.3	77.5	89.6

The seasonal pattern of nitrogen concentrations in streams follow monthly variation in river discharge (Figure 4.2.2.) and higher concentrations are detected in April as well as during winter. Nitrogen concentration in Pärnu-Oore station indicated some increasing tendency in 2009-2019 and the concentration of phosphorus decreased during the same time period.

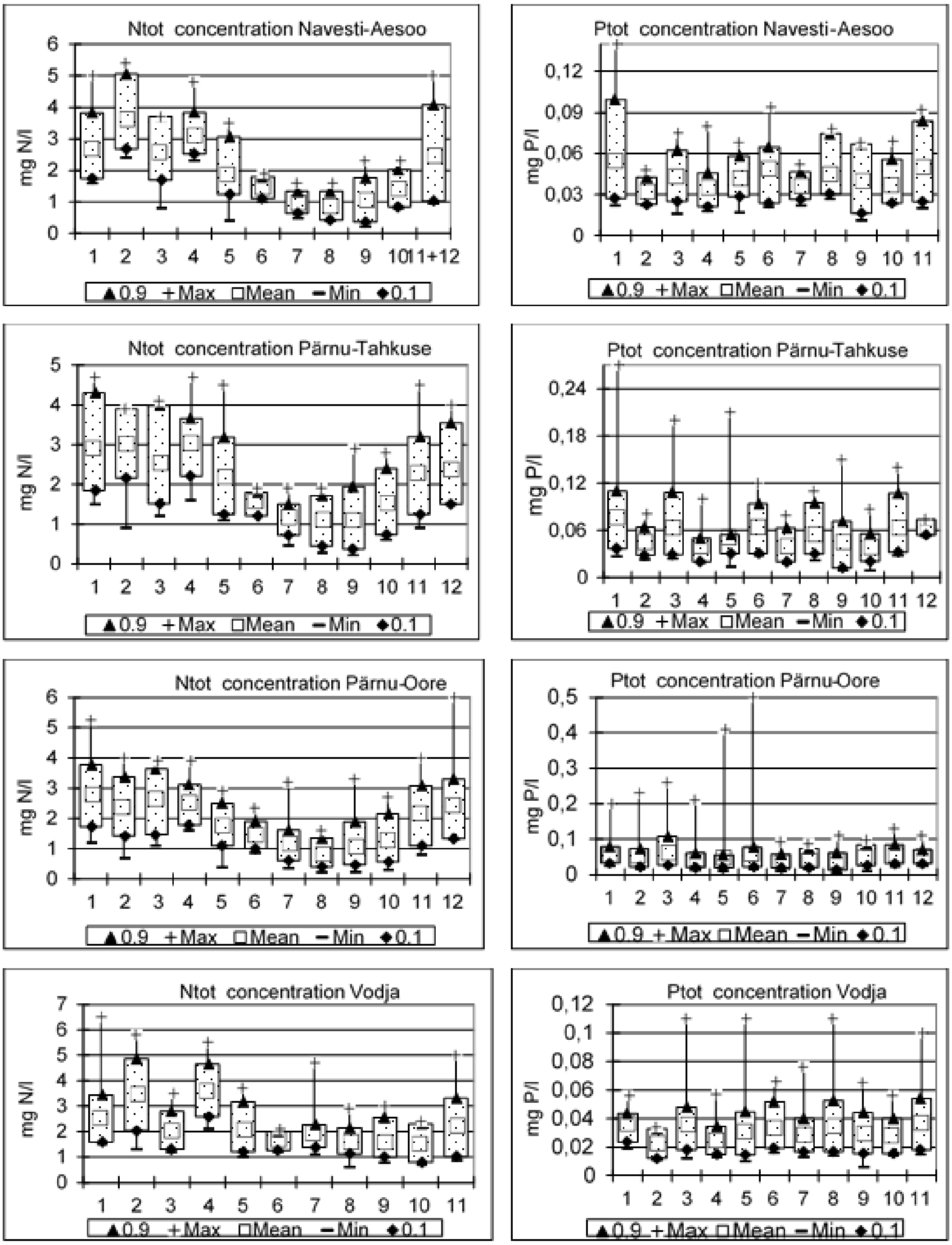


Figure 4.2.2. Ntot and Pot concentration in January-December 1993-2020.

Table 4.2.2.

Trends in concentrations in Pärnu-Oore station in winter time (December-February) 2009-2019.

NH_4-N		NO_3-N		PO_4-P		BOD_5	
MK-Stat	**p-value**	**MK-Stat**	**p-value**	**MK-Stat**	**p-value**	**MK-Stat**	**p-value**
0,06	0,476	0,59	0,278	**-2,23**	**0,013**	-0,12	0,454
Ntot		**Ptot**		**Q**			
MK-Stat	**p-value**	**MK-Stat**	**p-value**	**MK-Stat**	**p-value**		
0,63	0,265	-0,76	0,223	0,42	0,338		

4.3. Long-term changes of Salaca river basin

The flow characteristics of Salaca-Lagaste and Seda-Oleri are shown in Table 4.3.1.

Table 4.3.1.

Long-term flow data of Salaca/Salatsi and Seda rivers

Station	Basin area, km^2	Data series	Mean flow, m^3/s	Specific flow, l*s/km^2	Max flow		Min flow	
					Q, m^3/s	Date	Q, m^3/s	Date
Salaca-Lagaste	3220	1961-2019	31.62	9.82	312	28 March 1968	0.77	07 July 1971
Seda-Oleri	431	1979-2019	3.80	8.83	28.37	13 April 2011	0.25	22 May 2019

The mean annual Base Flow Index (BFI) of the river in the Salaca/Salatsi River Basin in 2002-2019 is quite high due to water storage in the Burtnieku Lake (Salaca-Mazsalaca, Salaca-Lagaste) and wetlands. BFI is smaller for Ruja River where wetlands' share is less than in other river basins (Table 4.3.2.).

Table 4.3.2.

Base flow index for rivers within Salaca/Salatsi River Basin in 2002-2019.

River - Station	BFI
Salaca - Mazsalaca	0.89
Salaca - Lagaste	0.81
Seda - Oleri	0.79

Ruja - Vilnisi	0.58

The climate change impact is not significant for the annual flow that is increasing slowly. However, changes of maximum flow are sufficiently large, it is decreasing due to increasing winter temperature (Fig. 4.2.1). The winter (December - February) seasonal flow is highly increased from 1961, and in the Salaca River the winter' mean flow changed from 26.7m^3/s (1927-1960) to 38.1 m^3/s (1961-2019).

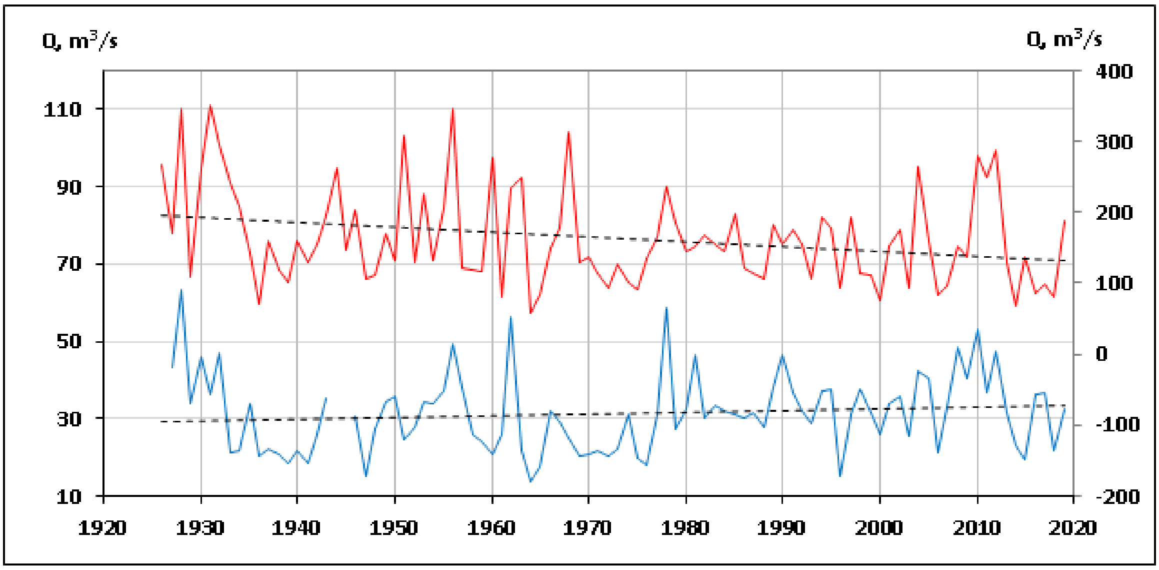


Figure 4.3.1. Long-term annual flow (blue line) and max flow (red line) data trend, Salaca/Salatsi near Lagaste.

Median values and variability of nutrient and BOD5 concentrations in the Salaca River 0.5 km upstream Salacgrīva are summarized in Table 4.3.3. Long-term changes of aquatic chemistry in the Seda River is not analysed in this report because there are too few monitoring data.

Table 4.3.3.

Concentrations of nutrients and BOD5 in Salaca River upstream Salacgrīva (1990-2019).

	Q, m3/s	TN, mg/L	N/NH$_4^+$, mg/L	TP, mg/L	BOD5, mg/L
Min	4.0	0.14	0.00	0.024	0.57
25th percentile	13.2	1.10	0.03	0.038	1.00
Median	28.3	1.62	0.04	0.047	1.30
Average	32.8	1.71	0.05	0.052	1.51
75th percentile	47.4	2.18	0.07	0.063	1.69
Max	120.9	4.75	0.30	0.163	5.50

The long-term data of nutrient and BOD5 concentrations in the Salaca River are shown in Fig.4.3.2. TN concentrations show a statistically significant decreasing trend (Table 4.3.2.). They are decreasing at a magnitude -0.0115 mg/L per year ($p=0.002$). Analysis of seasonal trends shows that TN concentrations are significantly ($p<0.05$) decreasing in April, May and July. Ammonium concentrations are also decreasing at a rate -0.0008 mg/L per year ($p=0.000$). Analysis of seasonal trends reveal that most significant reductions have occurred during winter and spring. TP concentrations are decreasing as well, but this trend is not statistically significant. Statistically significant decrease of TP content has been observed in August. Water discharge and BOD5 content show an increasing tendency since 1990, but it is not statistically significant. Seasonal analysis reveals that in March and September increase of BOD5 concentrations is statistically significant ($p<0.05$). Changes in discharge do not have an impact on the long-term trends of aquatic chemistry, because Mann-Kendall test values do not differ from partial Mann-Kendall test values. In this analysis, daily discharge of the aquatic chemistry sampling day was considered (Table 4.3.4.).

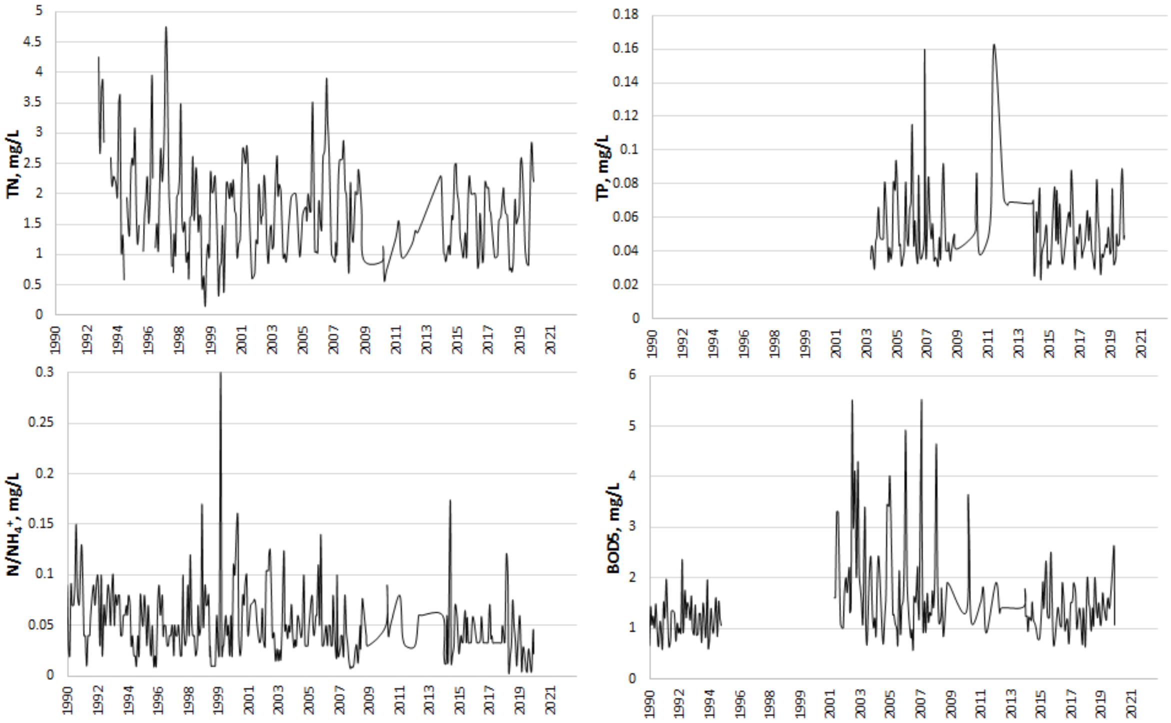


Figure 4.2.2. Long-term changes of nutrient and BOD5 concentrations.

Table 4.3.4.

Long-term changes of nutrient and BOD5 concentrations in the Salaca River (1990-2019).

	Q, m3/s	TN, mg/L	NNH4, mg/L	TP, mg/L	BOD5, mg/L
Sen's slope, units/year	0.028	**-0.0115**	**-0.0008**	-0.0002	0.005
Mann-Kendall statistics value	0.256	**-2.134**	**-3.509**	-1.607	0.945
Partial Mann-Kendall statistics value	-	**-2.137**	**-3.056**	-1.611	0.947

Partial Mann-Kendall p value	-	**0.016**	**0.001**	0.053	0.172

The average flow-adjusted loads and area-specific loads are summarized in Table 4.3.5. It should be noted that for Seda River monitoring data were available only for 2015. In general, area-specific loads are slightly lower in Seda than in Salaca, except for NNH_4^+.

Table 4.3.5.

Flow-adjusted mean load of nutrients and BOD_5 at monitoring stations in 2014-2019.

	TN	NNH4	TP	BOD5
Salaca upstream Salacgrīva				
Mean load, t/year	1847	41	50	1351
Mean area-specific load, kg/ha/y	5.42	0.12	0.15	3.96
Seda at mouth				
Mean load, t/year	232	8.0	5.9	156
Mean area-specific load, kg/ha/y	4.03	0.14	0.10	2.72

Monthly loads of NNH_4^+ show a statistically significant trend for the period 1990-2019 and 2009-2019 due to impact of water discharge. When the trend is corrected for the influence of water discharge (hydrological regime), the trend is still decreasing but with low significance. Loads of TN and TP are decreasing during 1990-2019 and when the impact of the hydrological regime is corrected, the trend is statistically significant. However, for 2009-2019, monthly loads of TN and TP show an increasing tendency (not statistically significant), when the trend is corrected for influence of hydrological regime. This increasing trend could possibly be attributed to anthropogenic pressures in the catchment area. BOD5 loads do not show statistically significant trends (Table 4.3.6.).

Table 4.3.6.

Long-term changes of monthly loads of nutrients and BOD5 in the Salaca River (*one-sided test, statistically significant if p<0,05, bold).*

	TN	NNH4	TP	BOD5
1990-2019				
Mann-Kendall statistics value	-1.098	**-2.223**	-1.197	0.271
Mann-Kendall p value	0.272	**0.026**	0.231	0.786
Partial Mann-Kendall statistics value	**-2.049**	**-3.177**	**-2.335**	-0.203
Partial Mann-Kendall p value	**0.041**	**0.001**	**0.020**	0.839

2009-2019				
Mann-Kendall statistics value	-0.617	**-2.198**	-1.269	-1.152
Mann-Kendall p value	0.537	**0.028**	0.205	0.249
Partial Mann-Kendall statistics value	1.489	-1.004	0.688	1.188
Partial Mann-Kendall p value	0.137	0.315	0.491	0.235

- **4.4. Long-term changes of Pärnu river basin**

Table 4.4.1. and Figure 4.4.1. summarize the water quality monitoring data of the content of nutrients and BOD_5 in rivers in 1993-2019 and additionally at the station Pärnu-Oore in 2009-2019 (Table 4.4.2.). The results indicate that organic pollution is not a real problem in studied rivers anymore. The content of dissolved oxygen is high and concentration of BOD and ammonium nitrogen is low. The mean content of BOD_5 is below 1.5 mg O_2/l in all studied streams and monitoring stations in 2009-2019 indicating a very good status by this parameter. The 90th percentile of NH_4-N concentrations is below 0.1 mg/l in the rivers Pärnu, Navesti, Halliste, Reiu and Vodja, that corresponds to very good status by ammonia and exceed this level only in the river Sauga (0.14 mgN/l), which corresponds to good status by this indicator. Moreover, the concentration of BOD_5 and NH_4-N in the rivers showed a statistically significant downward trend since 1993 and as well as during the more recent period 2009-2019 (Table 4.4.3.).

Higher mean N_{tot} levels were detected in the Pärnu-Türi and Vodja-Vodja stations (3.1 and 2.2 mg N/l, respectively). The ecological status of the river Pärnu-Oore station by N_{tot}, as well as the river Sauga is good, being even very good in the river Reiu. Mean content of Ptot is equal or below 0.08 mgP/l indicating good status by phosphorous of all the studies streams. Maximum levels and 0.9 percentile of Ptot concentrations is higher in the Sauga river.

Table 4.4.1.

Content of nutrients and BOD_5 in studied rivers and monitoring stations in 1993-2019.

N_{tot}	**Vodja**	**Pärnu-Türi**	**Pärnu-Tahkuse**	**Halliste**	**Navesti**	**Pärnu-Oore**	**Reiu**	**Sauga**
0.9 percentile	3.6	4.4	3.5	2.2	3.7	3.1	2.0	3.3
Max	6.5	5.0	4.7	3.6	5.4	6.0	4.0	8.0
Mean	2.2	3.1	2.0	1.4	2.0	1.9	1.3	2.0
Min	0.6	1.8	0.2	0.2	0.2	0.2	0.2	0.4
0.1 percentile	1.2	2.0	0.9	0.5	0.8	0.7	0.5	0.8
P_{tot}								
0.9 percentile	0.05	0.05	0.09	0.08	0.07	0.08	0.06	0.11

Max	0.16	0.06	0.27	0.16	0.14	0.50	0.33	0.67
Mean	0.03	0.04	0.05	0.05	0.04	0.05	0.04	0.08
Min	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02
0.1 percentile	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.04
BOD_5								
0.9 percentile	1.8	1.1	2.3	2.3	2.3	2.1	2.3	2.4
Max	2.7	1.1	4.3	4.5	4.3	5.2	7.1	6.1
Mean	1.2	0.7	1.5	1.5	1.5	1.4	1.5	1.7
Min	0.3	0.5	0.4	0.5	0.5	0.4	0.4	0.3
0.1 percentile	0.6	0.5	0.8	0.9	0.9	0.6	0.7	1.0
NH_4-N								
0.9 percentile	0.136	0.108	0.148	0.180	0.167	0.072	0.200	0.353
Max	0.500	0.120	0.720	0.690	0.560	0.660	0.800	0.900
Mean	0.063	0.056	0.063	0.061	0.063	0.047	0.074	0.119
Min	0.002	0.011	0.002	0.002	0.002	0.002	0.002	0.002
0.1 percentile	0.015	0.020	0.010	0.008	0.010	0.010	0.011	0.019
NO_3-N								
0.9 percentile	3.25	4.00	2.60	1.30	2.26	2.30	1.00	1.93
Max	4.40	4.80	3.70	3.00	4.90	3.90	2.20	4.60
Mean	1.55	2.63	1.26	0.62	1.08	1.11	0.50	0.97
Min	0.14	1.40	0.02	0.00	0.01	0.01	0.01	0.00
0.1 percentile	0.56	1.51	0.23	0.10	0.20	0.16	0.06	0.16
PO_4-P								
0.9 percentile	0.035	0.030	0.054	0.051	0.032	0.038	0.023	0.074
Max	0.092	0.032	0.190	0.720	0.110	0.150	0.071	0.620
Mean	0.018	0.019	0.029	0.029	0.018	0.020	0.015	0.043
Min	0.001	0.008	0.001	0.003	0.003	0.001	0.002	0.005
0.1 percentile	0.007	0.010	0.006	0.007	0.006	0.005	0.005	0.016

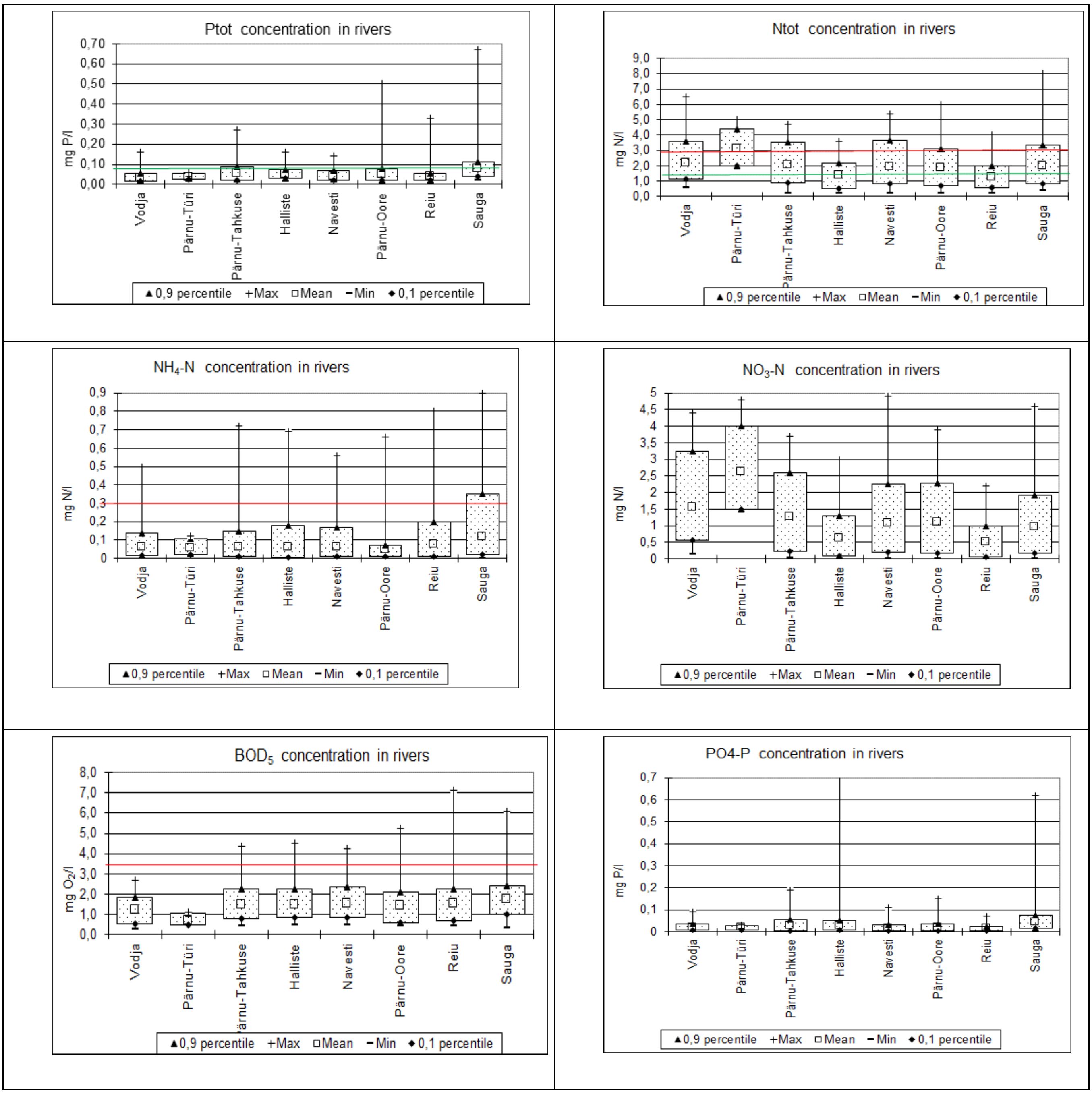


Figure 4.4.1. Content of nutrients and BOD_5 in rivers in 1993-2019.

Tabel 4.4.2.

The content of N_{tot}, P_{tot} and BOD_5 in the river Pärnu-Oore station in 2009-2019.

Ntot	Ntot	Ptot	BOD5
0,9 percentile	3.1	0.06	1.9
Max	4.4	0.10	3.2
Mean	2.0	0.04	1.1
Min	0.4	0.01	0.4

0,1 percentile	0.9	0.02	0.5

All rivers in Estonia are divided into nine river types depending on the catchment size, the content of humic substances in water and suitability for permanent fish population (Table 4.4.5.). Five water quality classes are defined within the river types based on the key indicators (dissolved oxygen¸ pH, BOD, NH_4^+-N, N_{tot} and P_{tot}).

1) Type V1A-KaVo – dark colored and humic-rich (COD_{Mn} 90%th percentile >25 mgO/l), catchment size 10–100 km^2; formation of permanent fish population is not possible due to periodic shortage of water;
2) Type V1A – dark colored and humic-rich (COD_{Mn} 90%th percentile >25 mgO/l), catchment size 10–100 km^2; formation of permanent fish population is possible;
3) Type V1B-KaVo – clearwater and low humic content (COD_{Mn} 90%th percentile <25 mgO/l), catchment size suurusega 10–100 km^2; formation of permanent fish population is not possible due to periodic shortage of water;
4) Type V1B- – clearwater and low humic content (COD_{Mn} 90%th percentile <25 mgO/l), catchment size suurusega 10–100 km^2; formation of permanent fish population is possible;
5) Type V2A – dark colored and humic-rich (COD_{Mn} 90%th percentile >25 mgO/l), catchment size >100–1000 km^2;
6) Type V2B – clearwater and low humic content (COD_{Mn} 90%th percentile <25 mgO/l catchment size >100–1000 km^2;
7) Type V3A – dark colored and humic-rich (COD_{Mn} 90%th percentile >25 mgO/l), catchment size >1000–10 000 km^2;
8) Type V3B – clearwater and low humic content (COD_{Mn} 90%th percentile <25 mgO/l), catchment size >1000–10 000 km^2;
9) Type V4B catchment size > 10 000 km^2 (River Narva).

Table 4.4.3.

Quality classes of rivers in Estonia by physical-chemical criteria.

Indicator		**Unit**	**High**	**Good**	**Moderate**	**Poor**	**Bad**
Type V1A, V1A-KaVo, V2A ja V3A							
O_2 saturation	10^{th} percentile	%	>60	<60–50	<50–40	<40–35	<35
BOD5	Arithmetic mean	mgO_2/l	<2,2	2,3-3,5	3,6-5,0	5,1-7,0	≥7,1
N_{tot}	Arithmetic mean	mgN/l	≤1,5	1,6-3,0	3,1-6,0	6,1-8,0	≥8,1
P_{tot}	Arithmetic mean	mgP/l	≤0,050	0,051–0,080	0,081–0,100	0,101–0,120	≥0,121
NH_4^+	90^{th} percentile	mgN/l	≤0,10	0,11-0,30	0,31-0,45	0,46-0,60	≥0,61
pH		pH unit	6–9	–	–	–	<6 or >9
Type V1B, V1B-KaVo, V2B and V3B							

O_2 saturation	10th percentile	%	≥ 70	69–60	59–50	49–40	≤39
BOD5	Arithmetic mean	mgO2/l	≤1,8	1,8–3,0	>3,0–4,0	>4,0–5,0	≥5,1
Ntot	Arithmetic mean	mgN/l	≤1,5	1,6-3,0	3,1-6,0	6,1-8,0	≥ 8,1
Ptot	Arithmetic mean	mgP/l	≤0,050	0,051–0,080	0,081–0,100	0,101–0,120	≥0,121
NH_4^+	90th percentile	mgN/l	≤0,10	0,11-0,30	0,31-0,45	0,46-0,60	≥0,61
pH		pH unit	6–9	–	–	–	<6 or >9
Type V4B: catchment size > 10 000 km^2 (River Narva)							
O_2 saturation	10th percentile	%	≥70	69–60	59–50	49–40	≤ 39
BOD5	Arithmetic mean	mgO2/l	≤1,8	1,9–3,0	3,1–4,0	4,1–5,0	≥5,1
Ntot	Arithmetic mean	mgN/l	≤0,5	0,6–0,7	>0,8–1,0	>1,1–1,5	≥1,5
Ptot	Arithmetic mean	mgP/l	≤0,040	0,041–0,060	0,061–0,080	0,081–0,100	≥0,101
NH_4^+	90th percentile	mgN/l	≤0,10	0,11-0,30	0,31-0,45	0,46-0,60	≥0,61
pH		pH unit	6,0–9,0	6,0–9,0	6,0–9,0	6,0–9,0	<6,0 or >9,0

According to the 2019 assessment of water bodies (Environmental Agency, Table 4.4.4.) the ecological status of the river Pärnu is moderate, mainly due to damming of rivers as an obstacle for fish migration. The status of the rivers Sauga and Reiu is good or having a good ecological potential at the upstream parts. All other water bodies are of fair status, except for the downstream part of the river Halliste, with bad status. The reason for not good status is either damming or high content of nutrients or both.

Table 4.4.4.

Ecological status of water bodies in the river Pärnu catchment in 2019 (Data: Environmental Agency).

Water body	Category	Type	Ecological status 2019	Reasons for not good status 2013-2019
Esna_1	HMW	V1B	Fair EP	Damming
Esna_2	Natural	V2B	Fair	Damming
Halliste_1	Natural	V1B	Fair	Nutrients, damming
Halliste_2	Natural	V2B	Fair	Nutrients, damming
Halliste_3	Natural	V3A	Poor	Downstream damming
Navesti_1	HMW	V1B	Fair EP	Morphology
Navesti_2	Natural	V1B	Fair	Damming

Navesti_3	Natural	V3B	Fair	Damming
Navesti_4	Natural	V3B	Fair	Unclear
Pärnu_1	Natural	V1B	Fair	Damming
Pärnu_2	Natural	V2B	Fair	
Pärnu_3	Natural	V3B	Fair	unclear
Reiu_1	HMW	V1A	Good EP	
Reiu_2	Natural	V1A	Good	Damming
Sauga_1	HMW	V1A	Good EP	
Sauga_2	Natural	V1A	Good	
Sauga_3	Natural	V2A	Good	
Vodja_1	HMW	V1B	Fair EP	Damming
Vodja_2	Natural	V1B	Fair	Damming

High content of organic substances in water leads to more intensive colour, indicating the importance of humic substances as part of the organic material. The rivers with the colour 90th percentile above 120 mg/l Pt could be classified as dark coloured and humic rich. This level corresponds to 90th percentile of COD_{Mn} level 20 mgO_2/l and the 90th percentile of the total organic carbon content (TOC) of 15 mgC/l based on the recent monitoring data in Estonia. The studied rivers Halliste, Navesti, Pärnu-Oore, Pärnu-Tahkuse, Reiu and Sauga belong to type A (dark coloured and humic-rich) and the rivers Vodja and the upstream part of the river Pärnu (Türi-Alliku) to type B clearwater and low humic content (Table 4.4.5.).

Table 4.4.5.

Mean content of N_{tot}, P_{tot} and 90th percentile of humic substances, organic carbon and KHT_{Mn} in rivers in 2015-2019.

River	Station	Type	0.9 percentile of KHTMn, mgO/l	0.9 percentile of Colour, mg/l Pt	N_{tot}, mean	P_{tot} mean	N/P	Forest, %
Halliste	Riisa	3A	32.7	285	1.4	0.038	37	60
Navesti	Aesoo	2B	27.5	200	2.2	0.04	55	57.5
Pärnu	Oore	V3B	30	210	2	0.04	50	57.5
Pärnu	Türi-Alliku	V3B	21.8	116.2	2.8	0.04	70	-
Pärnu	Tahkuse	3B	-	158	2.07	0.046	45	56.1
Reiu	Lähkma	V1A	33	222.6	1.2	0.035	34	77.5
Sauga	Nurme	2A	41.5	200	2	0.06	33	56.1
Vodja	Vodja	V1B	13	70	2.6	0.028	93	35.5

There is a good relationship between the share of forest land cover in catchments and the content of N_{tot} and water colour (Figure 4.4.2.).

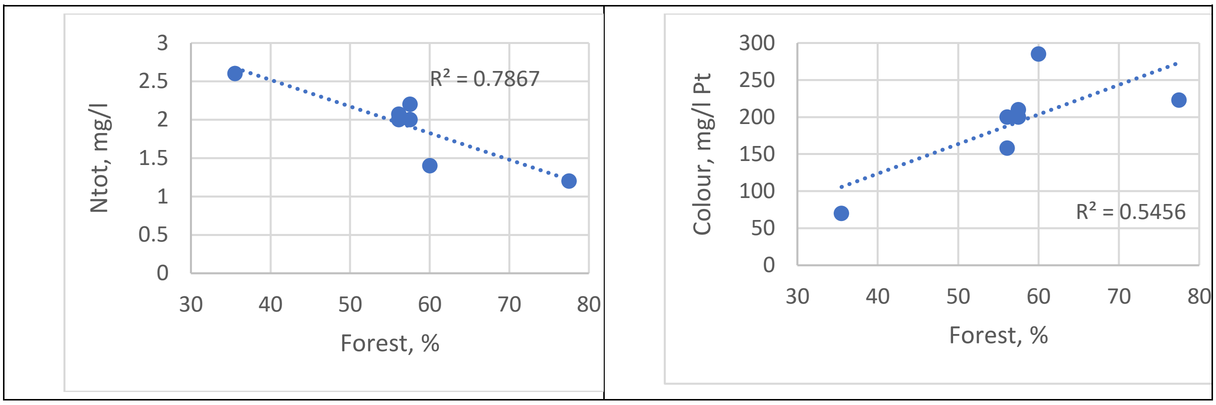


Figure 4.4.2. The share of forest land cover and the content of N_{tot} and water colour in studied catchments.

The area specific flow-adjusted mean annual load of nitrogen in 2014-2019 is considerably higher in the upstream tributary Vodja where it is 15 kg/ha/a (Table 4.4.6.). The area specific load of nitrogen decreases downstream of the river Pärnu being relatively lower in the rivers Reiu and Halliste.

Table 4.4.6.

Flow-adjusted mean load of nitrogen, phosphorus and BOD_5 at monitoring stations in 2014-2019.

River/station	**Mean load**	**Area specific load**	**River/station**	**Mean load**	**Area specific load**
	Tons/year	**kg/ha/a**		**Tons/year**	**kg/ha/a**
Pärnu-Oore			**Navesti-Aesoo**		
NH_4-N	41.5	0.08	NH_4-N	9.4	0.09
NO_3-N	3227.9	6.26	NO_3-N	686.5	6.59
N_{tot}	4118.0	7.99	N_{tot}	802.4	7.71
PO_4-P	22.8	0.04	PO_4-P	4.2	0.04
P_{tot}	59.4	0.12	P_{tot}	11.4	0.11
BOD_5	1694.4	3.29	BOD_5	361.4	3.47
Sauga-Nurme			**Halliste-Riisa**		
NH_4-N	14.2	0.26	NH_4-N	14.1	0.08
NO_3-N	281.1	5.15	NO_3-N	508.0	2.71
N_{tot}	415.4	7.61	N_{tot}	1015.0	5.42
PO_4-P	5.2	0.10	PO_4-P	6.7	0.04

P_{tot}	9.1	0.17	P_{tot}	19.3	0.10
BOD_5	287.6	5.27	BOD_5	653.1	3.49
Reiu-Lähkma			**Vodja-Vodja**		
NH_4-N	5.9	0.11	NH_4-N	0.8	0.16
NO_3-N	123.0	2.24	NO_3-N	69.6	13.65
N_{tot}	262.8	4.80	N_{tot}	76.5	15.00
PO_4-P	1.9	0.03	PO_4-P	0.25	0.05
P_{tot}	5.4	0.10	P_{tot}	0.5	0.10
BOD_5	209.7	3.83	BOD_5	16.4	3.22
Pärnu-Tahkuse					
NH_4-N	23.4	0.11			
NO_3-N	1482.0	7.16			
N_{tot}	1746.4	8.44			
PO_4-P	11.6	0.06			
P_{tot}	24.7	0.12			
BOD_5	736.2	3.56			

Nitrogen load correlates well with the share of agricultural and forest land area in the catchments (Figure 4.4.3.). Phsophorous load correlates with the share of wetlands in the catchments (Figure 4.4.4.)

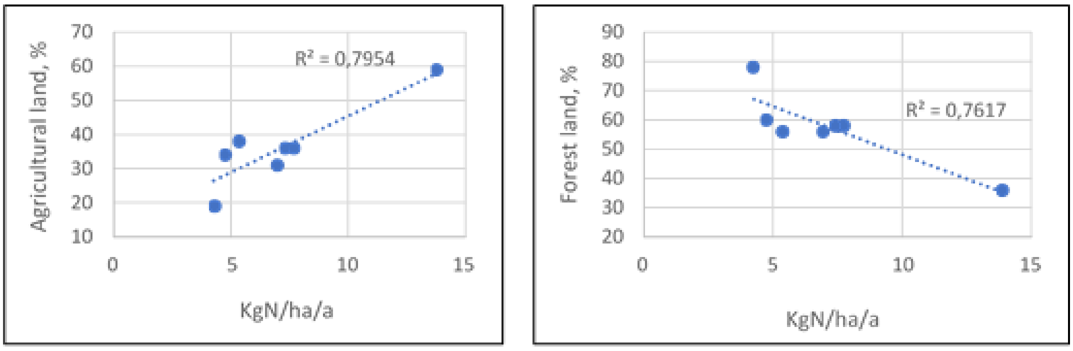


Figure 4.4.3. Correlation between the mean annual area-specific load of Ntot in 2014-2019 and the share of agricultural (left) and forest land cover types.

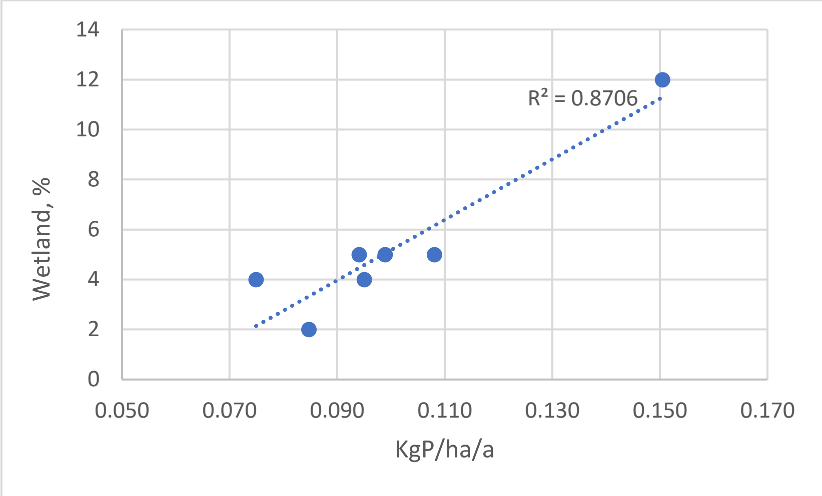


Figure. 4.4.4. Correlation between the mean annual area-specific load of Ptot in 2014-2019 and the share of wetland area in studied catchments.

Table 4.4.7.

The trend in nitrogen, phosphorus and BOD_5 load in studied rivers (MK-stat) and the trend corrected for the influence of discharge (PMK test) in 1993-2019 (*one-sided test, statistically significant if p<0,05, bold).*

Jõgi		**1993-2019**		**1993-2019**		**2009-2019**	
		MK-stat	**p-value**	**PMK**	**p-value**	**MK-stat**	**p-value**
Pärnu-Oore	NH_4-N	**-2,31**	**0,010**	**-2,86**	**0,002**	**-2,24**	**0,013**
	NO_3-N	**2,54**	**0,006**	**4,26**	**<0,001**	-0,83	0,205
	N_{tot}	1,59	0,055	**3,77**	**<0,001**	-0,85	0,196
	PO_4-P	**-1,96**	**0,025**	**-3,31**	**<0,001**	-1,54	0,062
	P_{tot}	-1,31	0,095	**-2,54**	**0,006**	-1,39	0,083
	BOD_5	**-1,94**	**0,026**	**-3,53**	**<0,001**	**-1,77**	**0,039**
	Q	-0,08	0,469			-1,61	0,054
Sauga-Nurme	NH_4-N	**-1,93**	**0,027**	-1,59	0,055	-0,45	0,327
	NO_3-N	0,84	0,200	**2,73**	**0,003**	0,38	0,350
	N_{tot}	0,28	0,389	**2,17**	**0,015**	-0,12	0,454
	PO_4-P	**-2,33**	**0,010**	**-2,24**	**0,013**	-0,22	0,410
	P_{tot}	**-1,83**	**0,034**	-1,59	0,056	-0,22	0,411
	BOD_5	-1,48	0,069	-1,00	0,158	-1,24	0,108
	Q	-1,11	0,134			-0,44	0,331
Reiu-Lähkma	NH_4-N	**-2,18**	**0,014**	**-2,90**	**0,002**	**-1,66**	**0,049**

	NO_3-N	0,43	0,334	0,36	0,359	0,21	0,416
	N_{tot}	0,29	0,385	0,11	0,457	-0,49	0,312
	PO_4-P	-1,39	0,083	**-2,44**	**0,007**	-1,47	0,070
	P_{tot}	-0,66	0,255	**-1,86**	**0,032**	-1,51	0,065
	BOD_5	-1,03	0,151	**-2,09**	**0,018**	-1,47	0,070
	Q	0,27	0,393			-1,07	0,142
Navesti-Aesoo	NH_4-N	-1,19	0,117	-1,45	0,073	-0,85	0,196
	NO_3-N	**2,78**	**0,003**	**3,70**	**<0,001**	1,14	0,126
	N_{tot}	**1,87**	**0,030**	**3,69**	**<0,001**	0,35	0,362
	PO_4-P	-1,55	0,060	**-2,04**	**0,021**	-0,33	0,369
	P_{tot}	-0,32	0,375	-0,76	0,223	-0,18	0,430
	BOD_5	-1,35	0,088	**-2,03**	**0,021**	**-1,76**	**0,039**
	Q	0,12	0,453			-1,33	0,089
Halliste-Riisa	NH_4-N	-1,61	0,053	**-2,21**	**0,013**	-0,48	0,315
	NO_3-N	**1,83**	**0,034**	**2,32**	**0,010**	-0,28	0,390
	N_{tot}	**1,74**	**0,041**	**3,05**	**0,001**	-0,75	0,228
	PO_4-P	**-2,01**	**0,022**	**-2,17**	**0,015**	0	0,5
	P_{tot}	**-1,98**	**0,024**	**-3,93**	**<0,001**	-0,81	0,209
	BOD_5	-1,28	0,100	**-2,73**	**0,003**	-1,58	0,057
	Q	0,26	0,399			-1,10	0,135
Pärnu-Tahkuse	NH_4-N	**-2,50**	**0,006**	**-2,48**	**0,007**	**-2,21**	**0,013**
	NO_3-N	**2,22**	**0,013**	**3,95**	**<0,001**	-1,36	0,087
	N_{tot}	0,68	0,249	**3,33**	**<0,001**	-1,36	0,087
	PO_4-P	**-2,17**	**0,015**	**-2,05**	**0,020**	**-1,69**	**0,046**
	P_{tot}	**-1,96**	**0,025**	**-1,76**	**0,039**	-1,02	0,153
	BOD_5	**-2,58**	**0,005**	**-2,86**	**0,002**	**-2,29**	**0,011**
	Q	-1,09	0,137			-1,54	0,061
Vodja-Vodja	NH_4-N	**-2,26**	**0,012**	**-3,62**	**<0,001**	-1,48	0,069
	NO_3-N	**3,15**	**<0,001**	**3,88**	**<0,001**	-0,42	0,338
	N_{tot}	**2,46**	**0,007**	**3,47**	**<0,001**	-0,49	0,311
	PO_4-P	**-1,80**	**0,036**	**-3,41**	**<0,001**	**-1,67**	**0,047**

	P_{tot}	-0,43	0,333	**-1,73**	**0,042**	-1,35	0,089
	BOD_5	**-1,80**	**0,036**	**-3,82**	**<0,001**	**-2,14**	**0,016**
	Q	0,88	0,189			**-1,70**	**0,044**

Statistically significant decreasing trend in NH_4-N and PO_4-P load since 1993 occurred during low flow period (May-July), for the latter also in January-March accompanied by the decrease in discharge. Decreasing trend in BOD_5 load occurred in March-July together with the decreasing tendency in discharge, indicating the reduced human-related load of organic substances. NO_3-N and N_{tot} load has had an increasing trend since 1993 during November-January and November-December months, respectively. This trend can only partly be explained by some increase in the river discharge, particularly in December.

Statistically significant decreasing trend in NH_4-N, PO_4-P and P_{tot} load since 1993 occurred during summertime (May-July) together with the decreasing trend in discharge, although according to the PMK test decreasing emissions of these compound to the streams played an important role. Increasing trend in NO_3-N and N_{tot} load have been particularly evident in November-December, and can only partly be explained by increasing trend in discharge during these months.

Decreasing trend in NH_4-N, P_{tot}, PO_4-P and BOD_5 load in the River Reiu by PMK test is particularly observable during warm season from May to August that cannot be explained only by the decreasing trend in discharge during this period, therefore indicating a reduced human impact to the river since 1993.

Table 4.4.8. provide statistics about the trends in nitrogen, phosphorus and BOD_5 load and discharge in studied rivers during low flow (vegetation) period in 2009-2019.

Table 4.4.8.

The trend in nitrogen, phosphorus and BOD_5 load and discharge in studied rivers during low flow (vegetation) period (MK-stat) in 2009-2019 (*one-sided test, statistically significant if p<0,05, bold)*.

River		**MK-stat**	**p-value**
Pärnu-Oore	NH_4-N	**-2.40**	**0.008**
	NO_3-N	-1.55	0.060
	N_{tot}	-1.43	0.076
	PO_4-P	**-2.00**	**0.023**
	P_{tot}	-1.52	0.064
	BOD_5	**-2.33**	**0.010**
	Q	**-1.80**	**0.036**
Sauga-Nurme	NH_4-N	-0.34	0.367
	NO_3-N	-0.10	0.462

	N_{tot}	-0.71	0.238
	PO_4-P	0.09	0.462
	P_{tot}	0.20	0.419
	BOD_5	-1.02	0.154
	Q	**-1.72**	**0.042**
Reiu-Lähkma	NH_4-N	**-2.24**	**0.013**
	NO_3-N	-0.95	0.172
	N_{tot}	-1.49	0.069
	PO_4-P	-1.39	0.083
	P_{tot}	-1.42	0.078
	BOD_5	-1.40	0.081
	Q	-1.51	0.066

5. Daily allowable maximum loads and their exceedance in the Salaca river catchment

The graphs of actual instantaneous loads calculated from ambient water quality and daily flow data at the time of sampling in monitoring stations of the studied rivers are provided below. These loads are compared with the Daily Allowable Maximum Load (DAML) of TN and TP during the same day at the monitoring station. The DAML of nitrogen and phosphorus should not exceed the level of good (red line) or high (yellow line) status by TN and TP over different hydrological periods. Maximum allowed concentrations (water quality target) of TN and TP are defined as <3.0 and <2.0 mg N/L for total nitrogen, <0.09 and <0.06 (for Seda River) or <0.045 (for Salaca River) mgP/L for total phosphorus, <0.24 and <0.16 mg/L in Seda and <0.16 and <0.10 mg/L in Salaca for NNH4 as well as <3.0 and <2.0 mg O2/L for BOD5 as annual mean concentrations (Table 4.3.3.). Provided target values are multiplied by discharge to get e.g. DAML of compounds.

The daily load of TN and TP is given on the vertical axis and exceedance frequency (P) is given on the horizontal axis. Loads above the curve indicate an exceedance of the water quality criterion, while those below the load duration curve show compliance (Fig.5.1. and 5.3.). diff N, diff P, diff NNH4 and diff BOD5 are percentage exceedances of the flow duration curve value and related exceedances in tons per day are marked with red shading (Tables 5.1-5.4.).

Ecological quality of the Salaca River has improved in recent years and since 2016 it is assessed as good (Table 5.5). Yearly average TN and TP concentrations correspond to high to good ecological quality, but NNH4 and BOD5 concentrations - to high ecological quality.

On average, observed loads of nutrients and BOD5 do not exceed the daily allowable maximum loads set by good/moderate quality class threshold concentrations (Tables 5.1-5.4.). However, daily loads of TN occasionally exceed DAML during mid-range to high flow periods (Fig.5.1). Daily loads also exceed DAML set by good/high quality class threshold concentrations during mid-range to high flow periods. Daily TP loads exceed DAML set by good/high quality class threshold concentrations, and the exceedances are more noticeable during mid to low water periods. Daily NNH4 and BOD5 loads do not exceed DAML set by good/high quality class threshold concentrations. However single observations can exceed the thresholds under all hydrological regimes.

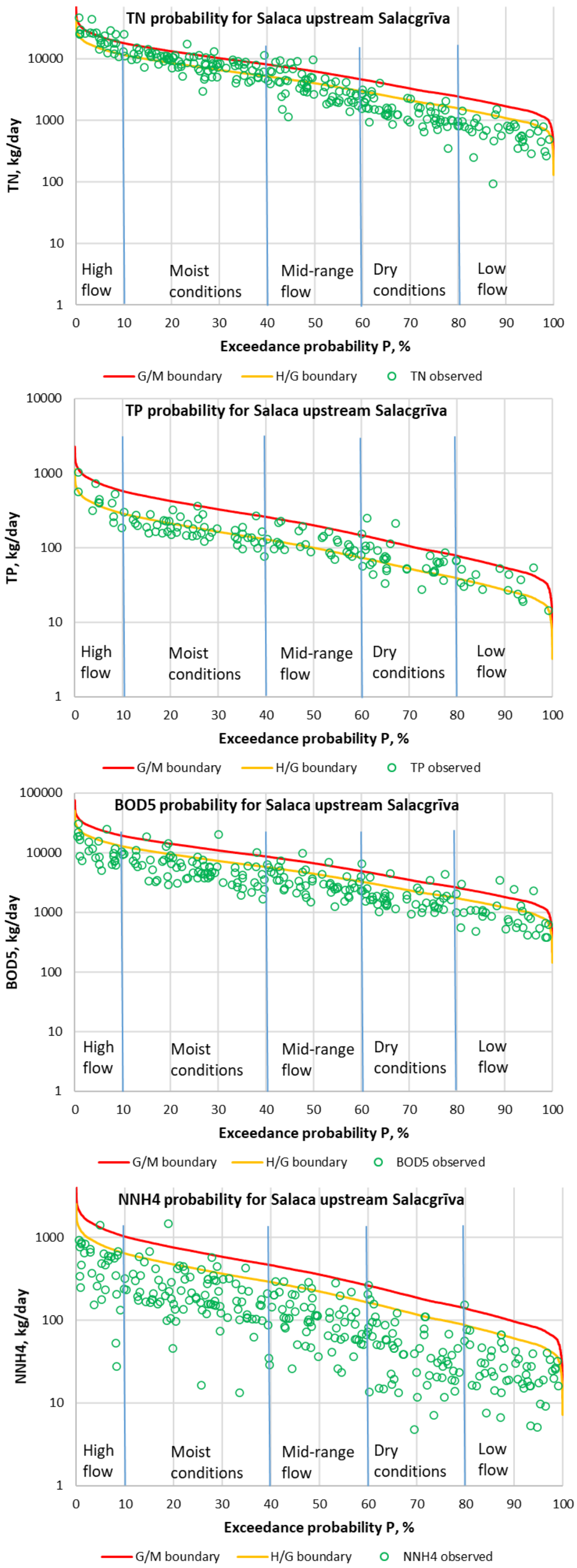


Figure 5.1. Comparison of the observed daily load in Salaca River with the maximum allowable daily loads corresponding to the good and high ecological status.

TN is the only parameter whose concentrations are discharge-dependent. River discharge explains about 38 % of variation in TN concentration. TP, BOD5 and NNH4 concentrations do not show a close relationship with discharge. Both the highest and lowest TP concentrations are observed during a low-flow period (Fig.5.2.).

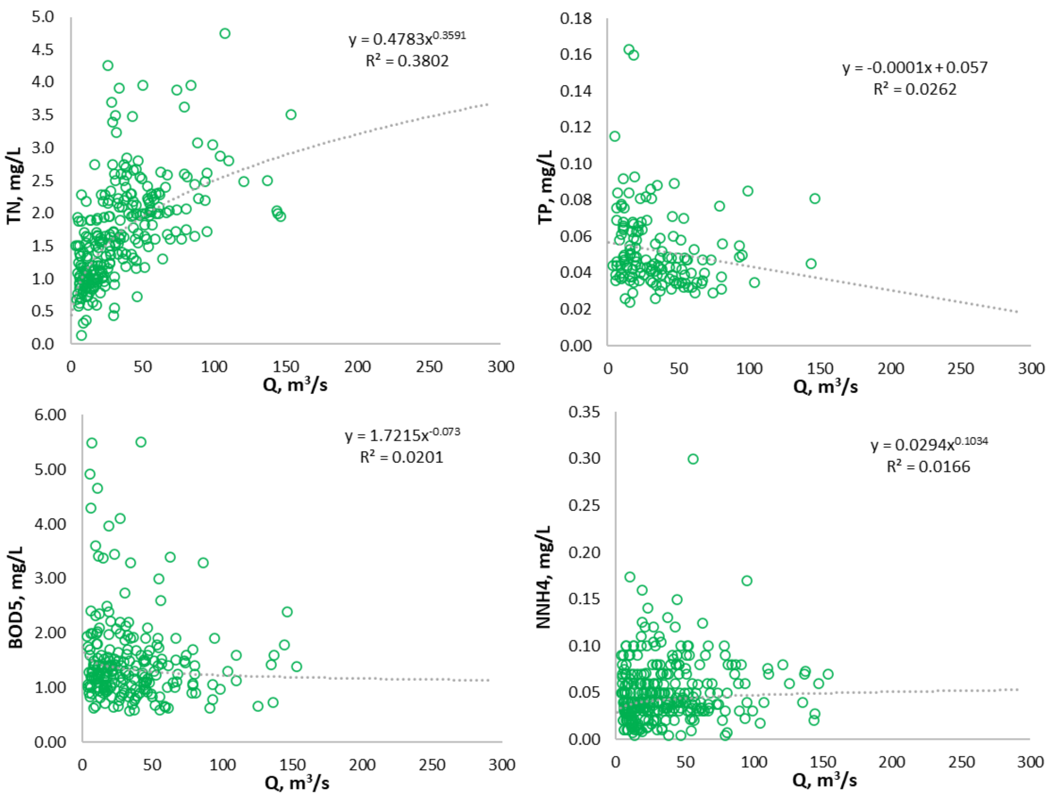


Figure 5.2. Correlation between river discharge and concentrations of chemical parameters.

Table 5.1.

Daily TN load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

P, %	median Q, m3/s	TN kg/day	TN (GM), kg/day	TN (HG), kg/day	diff TN (GM), kg/day	diff TN (HG), kg/day	diff TN (GM), %	diff TN (HG), %
0-10	94.5	22484	22865	14699	-380	7785	-1.7	53.0
10-20	63.1	11433	15260	9810	-3828	1623	-25.1	16.5
20-30	48.0	8262	11612	7465	-3350	797	-28.8	10.7
30-40	37.4	6822	9057	5822	-2235	1000	-24.7	17.2
40-50	29.2	4830	7067	4543	-2237	287	-31.7	6.3
50-60	22.1	2599	5342	3434	-2744	-835	-51.4	-24.3
60-70	16.0	1763	3877	2492	-2113	-729	-54.5	-29.2
70-80	11.7	1159	2824	1816	-1666	-657	-59.0	-36.2
80-90	8.4	788	2042	1313	-1254	-525	-61.4	-40.0
90-100	5.8	570	1400	900	-830	-330	-59.3	-36.7

Table 5.2.

Daily TP load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

P, %	median Q, m3/s	TP kg/day	TP GM), kg/day	TP (HG), kg/day	diff TP (GM), kg/day	diff TP (HG), kg/day	diff TP (GM), %	diff TP (HG), %
0-10	94.5	456	735	367	–279	88	-38.0	24.0
10-20	63.1	214	491	245	–276	–31	-56.3	-12.6
20-30	48.0	196	373	187	–177	10	-47.4	5.2
30-40	37.4	141	291	146	–151	–5	-51.7	-3.4
40-50	29.2	136	227	114	–91	22	-40.1	19.7
50-60	22.1	104	172	86	–68	18	-39.6	20.8
60-70	16.0	89	125	62	–35	27	-28.3	43.4
70-80	11.7	58	91	45	–33	13	-36.2	27.7
80-90	8.4	39	66	33	–27	6	-40.5	19.1
90-100	5.8	30	45	23	–15	7	-33.4	33.2

Table 5.3.

Daily NNH_4^+ load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

P, %	median Q, m3/s	NNH4 kg/day	NNH4 (GM), kg/day	NNH4 (HG), kg/day	diff NNH4 (GM), kg/day	diff NNH4 (HG), kg/day	diff NNH4 (GM), %	diff NNH4 (HG), %
0-10	94.5	496	1307	817	–811	–321	-62.1	-39.3
10-20	63.1	299	872	545	–573	–246	-65.7	-45.1
20-30	48.0	238	664	415	–425	–177	-64.1	-42.6
30-40	37.4	154	518	323	–363	–169	-70.2	-52.4
40-50	29.2	139	404	252	–265	–114	-65.6	-45.0
50-60	22.1	94	305	191	–211	–96	-69.1	-50.5
60-70	16.0	65	222	138	–156	–73	-70.6	-52.9
70-80	11.7	42	161	101	–120	–59	-74.2	-58.8
80-90	8.4	34	117	73	–83	–39	-70.9	-53.5
90-100	5.8	22	80	50	–58	–28	-71.9	-55.1

Table 5.4.

Daily BOD5 load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

P, %	median Q, m3/s	BOD5 kg/day	BOD5 (GM), kg/day	BOD5 (HG), kg/day	diff BOD5 (GM), kg/day	diff BOD5 (HG), kg/day	diff BOD5 (GM), %	diff BOD5 (HG), %
0-10	94.5	12342	24498	16332	-12156	-3990	-49.6	-24.4
10-20	63.1	7736	16350	10900	-8615	-3164	-52.7	-29.0
20-30	48.0	5405	12441	8294	-7036	-2889	-56.6	-34.8
30-40	37.4	4590	9704	6469	-5114	-1879	-52.7	-29.0
40-50	29.2	4020	7572	5048	-3552	-1028	-46.9	-20.4
50-60	22.1	2857	5724	3816	-2867	-959	-50.1	-25.1
60-70	16.0	2072	4154	2769	-2081	-697	-50.1	-25.2
70-80	11.7	1708	3026	2017	-1318	-309	-43.5	-15.3
80-90	8.4	1288	2188	1458	-900	-170	-41.1	-11.7
90-100	5.8	835	1500	1000	-665	-165	-44.3	-16.5

The Seda River was monitored only in 2007 and 2015 and its ecological quality has been assessed as good (Table 5.5). Due to insufficient number of monitoring data, it is possible to analyse single exceedances of DAML (Fig. 5.3.). Daily loads of TN exceeded the DAML set according to good/moderate quality class threshold during moist conditions, but TP loads exceeded DAML during dry conditions. No exceedances were observed for NNH4 and BOD5 concentrations.

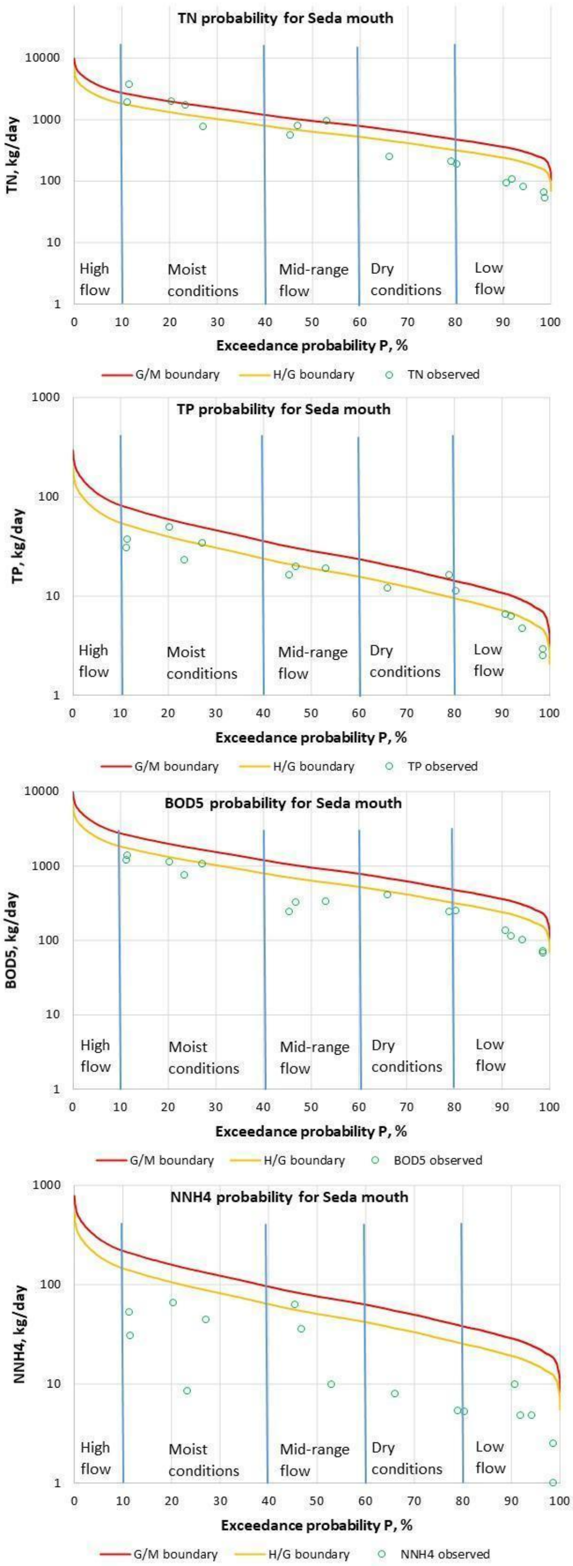


Figure 5.3. Comparison of the observed daily load in Seda River with the maximum allowable daily loads corresponding to the good and high ecological status.

Table 5.5.

Ecological quality changes in Salaca and Seda Rivers.

Year	Zoo-benthos	Macro-phytes	Fish	Fito-benthos	Total biology	O2	BOD5	NNH4	TN	TP	Total chemistry	Hymo_2020	TOTAL
Salaca 0.5 km upstream Salacgrīva													
2006	3		3		3	10.1	1.7	0.06	1.9	0.056	2	5	**3**
2007	3		2		3	11.9	1.8	0.04	2	0.065	2	5	**3**
2008	1	3	2		3	11.9	1.8	0.02	1.9	0.047	2	5	**3**
2009	3		3		3	11.5	1.4	0.05	1.8	0.041	2	5	**3**
2010			3		3	10.6	2.2	0.06	0.8	0.059	2	5	**3**
2011	3		3		3	10.9	1.4	0.05	1.3	0.093	3	5	**3**
2012	2		4		4	9.5	1.5	0.05	1.3	0.069	2	5	**4**
2014	2	2		1	2	11.45	1.25	0.044	1.41	0.049	2	5	**2**
2015	3	3	4	1	4	11.8	1.4	0.04	1.67	0.051	2	5	**4**
2016						10.85	1.19	0.039	1.41	0.053	2	5	**2***
2017						10.89	1.31	0.04	1.50	0.047	2	5	**2***
2018	1	1		2	2	11.1	1.3	0.05	1.4	0.044	1	5	**2**
2019						11.4	1.5	0.02	1.8	0.050	2	5	**2***
Seda at mouth													
2007		2			2	8.9	1.4	0.05	2.4	0.064	2	4	**2**
2015	2	2			2	9.5	1.2	0.062	1.58	0.051	1	4	**2**

6. Daily allowable maximum loads and their exceedance in the Pärnu river catchment

The graphs of actual instantaneous loads calculated from ambient water quality and daily flow data at the time of sampling in monitoring stations of the studied rivers are provided below. These loads are compared with the Daily Allowable Maximum Load (DAML) of N_{tot} and P_{tot} during the same day at monitoring station. The DAML of nitrogen and phosphorus should not exceed the level of good (blue line) or very good (grey line) status by N_{tot} and P_{tot} over different hydrological periods. Maximum allowed concentrations (water quality target) of N_{tot} and P_{tot} are defined as <1.5 and <3.0 mg N/l for nitrogen and <0.08 and <0.05 mgP/l for phosphorus as maximum annual mean concentrations for the streams with the catchment area less than 10,000 km^2 (Keskkonnaministri 24.04.2020. a määrus nr. 19). Provided target values are multiplied by discharge to get e.g. DAML of compounds.

The daily load of Ntot and Ptot is given on the vertical axis and exceedance frequency (P) is given on the horizontal axis. Loads above the curve indicate an exceedance of the water quality criterion, while those below the load duration curve show compliance. Ndiff and Pdiff are percentage exceedances of the flow duration curve value and related exceedances in tons per day are marked with red shading.

Sauga-Nurme

The ecological status of the River Sauga is good or having a good ecological potential at the upstream part of the stream (Table 18). The load of N_{tot} and P_{tot} show compliance with the target, i.e. good status for N_{tot} and P_{tot}, except minor exceedance during the wet season for N_{tot} (P=10-20%) (Figure 6.1., Table 6.1.). The measured instantaneous load of N_{tot} exceeds the water quality target of very good status by N during most of the seasons, particularly during high flow period with the flow exceedance probability 0-10%, reflecting potential impact from nonpoint sources. The sum of exceedances of the daily load is at least 40 tons, which should be decreased when aiming to achieve very good status by N_{tot}.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during high flow and wet season (P=0-20%), as well as the low flow and dry season (P=60-90%). The point sources contribute only 07% and 1.8% of the total riverine load of N and P respectively (Table7.2.2.1), but 12.2%and 9.5 % of the total N and P load during the dry season (P=90-100%), respectively (Table 7.2.1.1.).

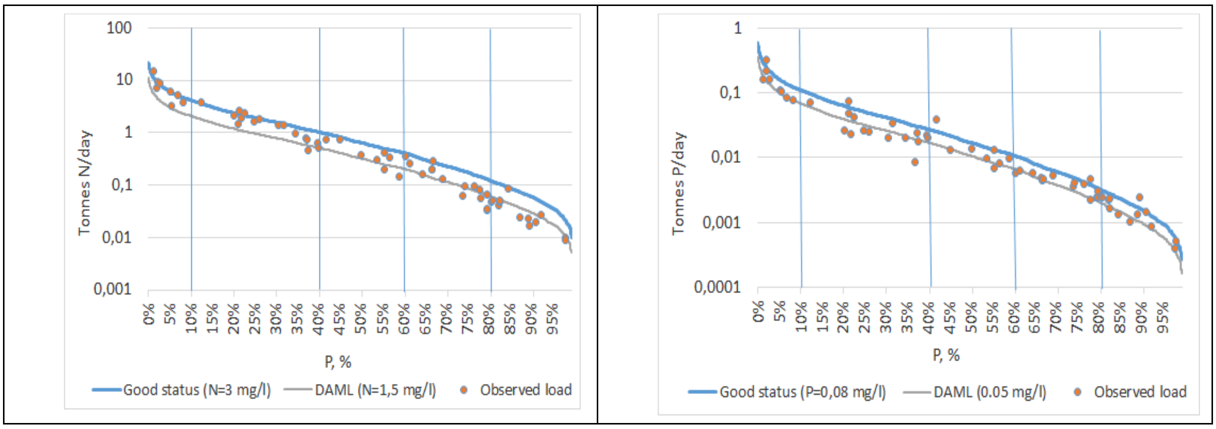


Figure 6.1. Load exceedance probability curves for N_{tot} (left) and P_{tot} (right).

Table 6.1.

Daily load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

Exceedance probability, %	N, tons/ day	DAML, tons (3 mg/l)	DAML, tons (1.5 mg/l)	P, tons/ day	P, 0.08 mg/l	P, 0.05 mg/l	Ndiff, tons (3.0 mg/l)	%	Ndiff, tons (1.5 mg/l)	diff %	Pdiff, tons (0.08 mg/l)	diff %	Pdiff, tons (0.05 mg/l)	diff %
0-10	58.8	59.3	29.6	1.24	1.58	0.99	-0.4	-0.01	29.2	0.50	-0.34	-0.27	0.252	0.20
10-20	3.7	3.6	1.8	0.07	0.10	0.06	0.1	0.03	1.9	0.52	-0.03	-0.38	0.010	0.14
20-30	13.8	16.6	8.3	0.27	0.44	0.28	-2.8	-0.20	5.5	0.40	-0.17	-0.65	-0.009	-0.03
30-40	6.4	8.8	4.4	0.15	0.23	0.15	-2.4	-0.38	2.0	0.31	-0.09	-0.60	0.000	0.00
40-50	2.4	3.4	1.7	0.09	0.09	0.06	-1.0	-0.44	0.7	0.28	-0.01	-0.07	0.028	0.33
50-60	1.4	2.4	1.2	0.05	0.06	0.04	-1.0	-0.75	0.2	0.13	-0.02	-0.34	0.008	0.16
60-70	1.6	2.1	1.1	0.04	0.06	0.04	-0.6	-0.36	0.5	0.32	-0.02	-0.53	0.002	0.04
70-80	0.4	0.9	0.5	0.02	0.03	0.02	-0.5	-1.20	-0.04	-0.10	0.00	-0.19	0.005	0.26
80-90	0.5	1.0	0.5	0.02	0.03	0.02	-0.6	-1.20	-0.05	-0.10	-0.01	-0.34	0.003	0.16
90-100	0.1	0.2	0.1	0.01	0.01	0.00	-0.1	-1.50	-0.02	-0.25	0.00	0.04	0.002	0.40

The analysis of N_{tot} and P_{tot} loads since 2009 did not reveal any statistically significant trend although there was a statistically significant decreasing trend in river runoff (Table 16). Thus, exceedances of the quality target of very good status can be related to human induced input of both nitrogen as well as phosphorous.

The long-term (2007-2019) mean daily BFI is 0.45, varying from 0.33 to 0.52, therefore indicating high seasonal and annual variability.

Actual fluctuation in nutrient loads has not been well described due to the fact that majority (72%) of the water samples (44 out of 61) collected since 2007 describe only 14% of N load and 19% of P load (Figure 6.2.). Only one water sample represents the streamflow exceedance probability of 10-20%, i.e. wet period.

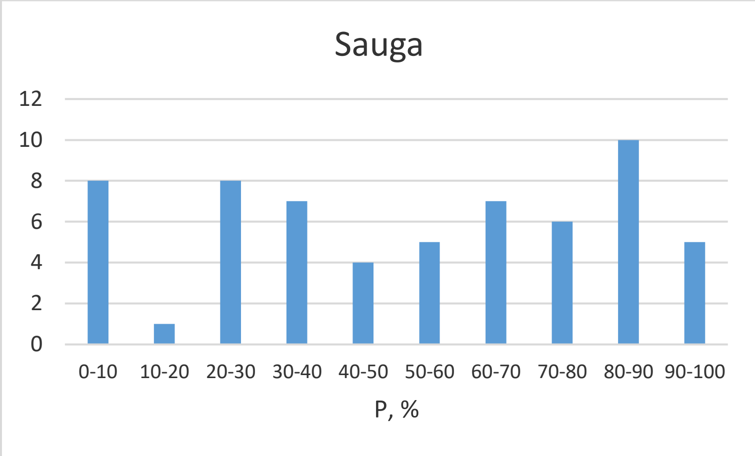


Figure 6.2. Number of water samples during hydrological period.

Reiu-Lähkma

The status of the River Reiu is good or having a good ecological potential at the upstream part of the stream (Table 13). The load of N_{tot} and P_{tot} show compliance with the target, i.e. good status for N_{tot} and very good status for P_{tot} (Figure 6.3., Table 6.2.). The measured instantaneous load of Ntot exceeds the water quality target of very good status by N during high flow period with the flow exceedance probability 0-30%, reflecting potential impact from nonpoint sources. The sum of exceedances of daily flows of N_{tot} load is at least 4.6 tons, which should be decreased aiming to achieve very good status by N_{tot} during that season. The point sources contribute only 0.4% and 1.8% of the total load of N and P (Table 7.2.2.1) but 3.8 and 3.6 % of the total N and P load during the dry season (P=90-100%), respectively (Table 7.2.1.1.).

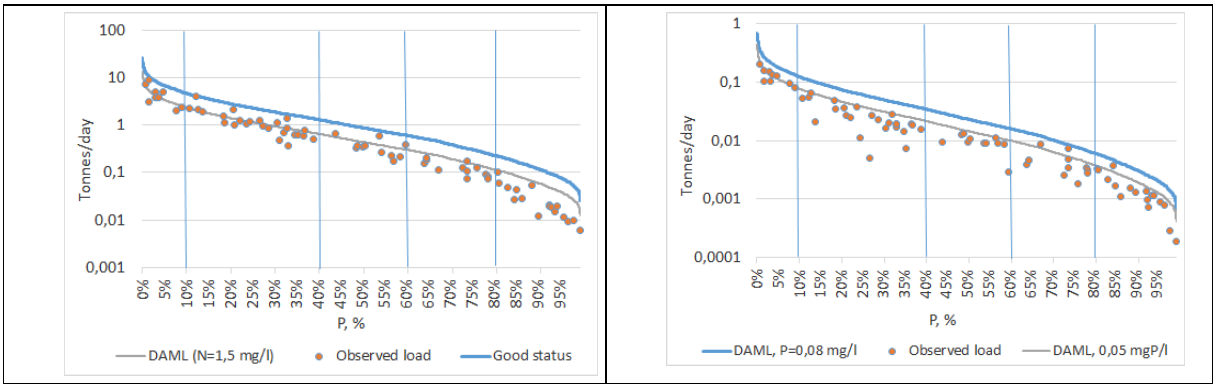


Figure 6.3. Load exceedance probability curves for N_{tot} (left) and P_{tot} (right).

Table 6.2.

Daily load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

Exceedance probability, %	N, tons / day	DAML, tons (3 mg/l)	DAML, tons (1.5 mg/l)	P, tons/day	P, 0.08 mg/l	P, 0.05 mg/l	Ndiff, tons (3.0 mg/l)	%	Ndiff, tons (1.5 mg/l)	diff %	Pdiff, tons (0.08 mg/l)	diff %	Pdiff, tons (0.05 mg/l)	diff %
0-10	41.0	76.6	38.3	1.17	2.04	1.28	-35.7	-0.87	2.6	0.06	-0.87	-0.74	-0.106	-0.09
10-20	12.9	22.4	11.2	0.28	0.60	0.37	-9.5	-0.73	1.7	0.13	-0.31	-1.12	-0.091	-0.32
20-30	9.8	19.0	9.5	0.20	0.51	0.32	-9.2	-0.94	0.3	0.03	-0.31	-1.58	-0.120	-0.61
30-40	8.1	17.9	9.0	0.20	0.48	0.30	-9.9	-1.22	-0.9	-0.11	-0.28	-1.42	-0.101	-0.51
40-50	1.4	2.9	1.5	0.04	0.08	0.05	-1.6	-1.15	-0.1	-0.07	-0.04	-1.23	-0.014	-0.39
50-60	2.2	5.2	2.6	0.07	0.14	0.09	-3.0	-1.38	-0.4	-0.19	-0.07	-1.07	-0.020	-0.29
60-70	1.0	2.6	1.3	0.02	0.07	0.04	-1.6	-1.49	-0.3	-0.24	-0.04	-1.78	-0.018	-0.74
70-80	0.9	2.3	1.2	0.03	0.06	0.04	-1.5	-1.74	-0.3	-0.37	-0.03	-1.11	-0.009	-0.32
80-90	0.4	1.3	0.6	0.02	0.03	0.02	-0.9	-2.51	-0.3	-0.75	-0.02	-1.00	-0.004	-0.25
90-100	0.1	0.8	0.4	0.01	0.02	0.01	-0.7	-4.60	-0.3	-1.80	-0.01	-1.40	-0.004	-0.50

The analysis of N_{tot} and P_{tot} loads over the monitoring period did not reveal any statistically significant trends (Table 4.4.7.) although the load of ammonia showed statistically significant decreasing trend, including in summer (Table 4.4.8.). P_{tot} load showed downward trend, although statistically less significant.

The long-term (2007-2019) mean daily BFI is 0.46, varying from 0.35 to 0.54, therefore indicating high seasonal and annual variability.

Actual fluctuation in nutrient loads has not been well described due to the fact that majority (69%) of the water samples (51 out of 74) collected since 2007 describe only 18% of N load and 19% of P load (Figure 6.4.).

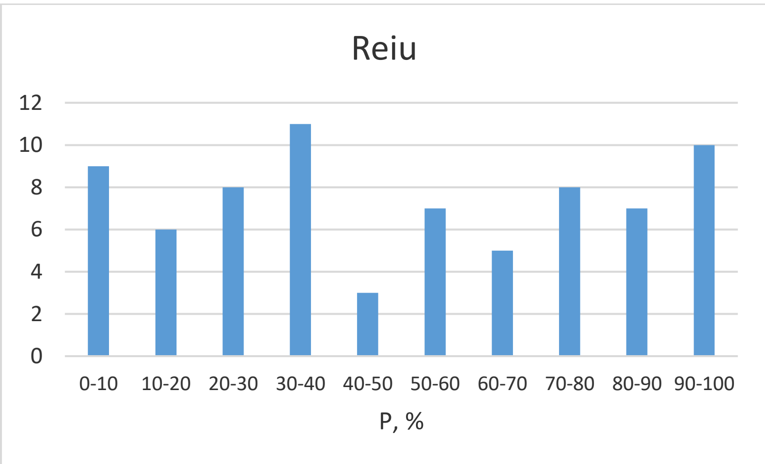
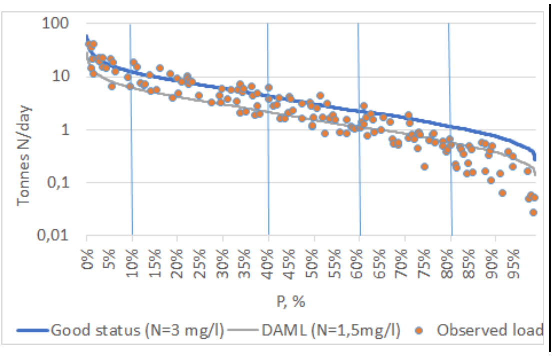


Figure 6.4. Number of water samples during hydrological period.

Pärnu-Tahkuse

The ecological status of the river Pärnu at Tahkuse station is fair (Table 4.4.4). The load of N_{tot} and P_{tot} show compliance with the target, i.e. good status for N_{tot} and P_{tot} (Figure 6.5., Table 6.3.). The measured instantaneous load of N_{tot} exceeds the water quality target of a very good status by N during most of the seasons reflecting potential impact from nonpoint and point pollution sources. The sum of exceedances of daily load is at least 308 tons, which should be decreased aiming to achieve very good status by N_{tot}.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during high flow season (P=0-10%), as well as the wet season and transition zone between moist and wet (P=20-70%) by 3.7 tons.



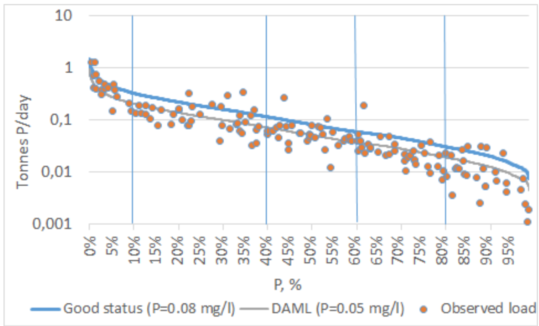


Figure 6.5. Load exceedance probability curves for N_{tot} (left) and P_{tot} (right).

Table 6.3.

Daily load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

Exceedance probability, %	N, tons/ day	DAML, tons (3 mg/l)	DAML, tons (1.5 mg/l)	P, tons/ day	P, 0.08 mg/l	P, 0.05 mg/l	Ndiff, tons (3.0 mg/l)	%	Ndiff, tons (1.5 mg/l)	diff %	Pdiff, tons (0.08 mg/l)	diff %	Pdiff, tons (0.05 mg/l)	diff %
0-10	358.0	388.9	194.5	9.1	10.37	6.48	-30.8	-0.1	163.6	0.5	-1.28	-0.14	2.61	0.29
10-20	107.3	114.2	57.1	1.5	3.05	1.90	-6.9	-0.1	50.2	0.5	-1.54	-1.02	-0.39	-0.26
20-30	81.1	88.5	44.3	1.7	2.36	1.48	-7.4	-0.1	36.9	0.5	-0.62	-0.36	0.26	0.15
30-40	70.1	83.3	41.6	1.8	2.22	1.39	-13.2	-0.2	28.5	0.4	-0.45	-0.25	0.38	0.22
40-50	43.5	53.0	26.5	1.0	1.41	0.88	-9.5	-0.2	17.0	0.4	-0.40	-0.40	0.13	0.12
50-60	31.1	48.8	24.4	0.9	1.30	0.81	-17.7	-0.6	6.7	0.2	-0.37	-0.40	0.12	0.12
60-70	21.2	34.4	17.2	0.7	0.92	0.57	-13.3	-0.6	4.0	0.2	-0.20	-0.28	0.15	0.20
70-80	12.5	23.3	11.7	0.3	0.62	0.39	-10.8	-0.9	0.9	0.1	-0.31	-1.01	-0.08	-0.25
80-90	7.1	19.0	9.5	0.3	0.51	0.32	-11.9	-1.7	-2.4	-0.3	-0.25	-0.96	-0.06	-0.22
90-100	2.1	6.8	3.4	0.1	0.18	0.11	-4.7	-2.3	-1.3	-0.6	-0.08	-0.78	-0.01	-0.11

The analysis of N_{tot} and P_{tot} loads over the monitoring period show statistically significant upward trend of nitrates and decreasing trend of ammonia since 1993 (Table 4.4.7.). The PMK test show statistically significant upward trend for total nitrogen, indicating possible human impact to upward trend. P_{tot} load showed statitically significant downward trend in 1993-2019, although statistically less significant decreasing trend since 2009.

The long-term (1993-2019) mean daily BFI is 0.63, varying from 0.45 to 0.78, therefore indicating rather high seasonal and annual variability.

Actual fluctuation in nutrient loads has not been well described due to the fact that majority (73%) of the water samples (112 out of 154) collected since 1993 describe only 26% of N load and 29% of P load (Figure 6.6.).

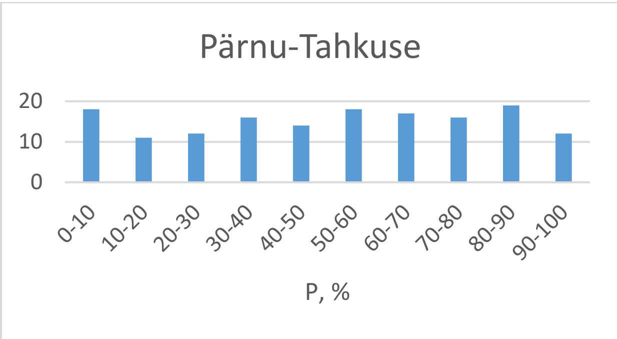


Figure 6.6. Number of water samples during hydrological period.

Pärnu-Oore

The ecological status of the river Pärnu at Oore station is fair (Table 4.4.4.). The load of N_{tot} and P_{tot} show overall compliance with the target, i.e. good status for N_{tot} and P_{tot}, although several exceedances of the load duration curve occur during high flow and wet seasons, as well as during transition zone for P_{tot} (Figure 6.7., Table 6.4.). The measured instantaneous load of N_{tot} exceeds the water quality target of very good status by N during most of the seasons reflecting potential impact from nonpoint pollution sources. The sum of exceedances of daily load is at least 1267 tons, which should be decreased aiming to achieve very good status by N_{tot}.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during the high flow season (P=0-10%), as well as the transition zone between moist and wet (P=50-60%) by 3.4 tons.

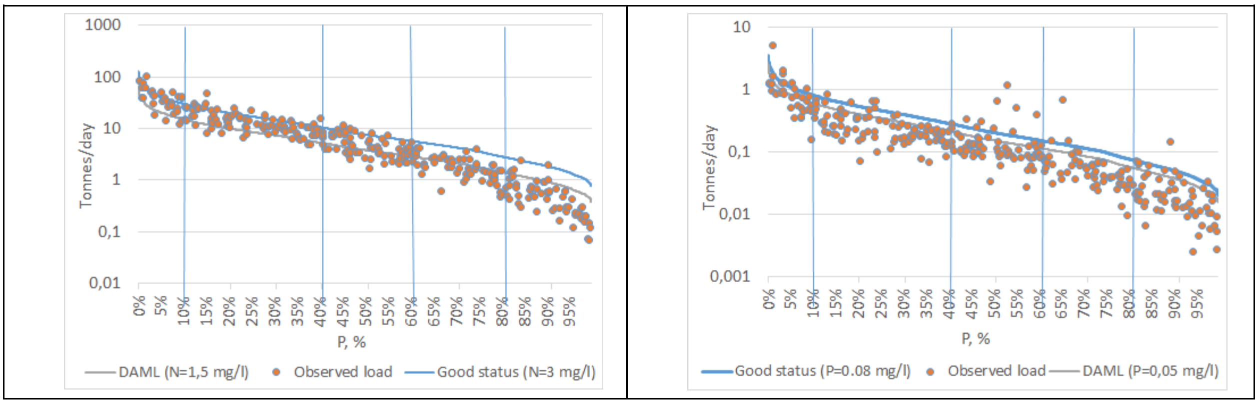


Figure 6.7. Load exceedance probability curves for N_{tot} (left) and P_{tot} (right).

Table 6.4.

Daily load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

Exceedance probability, %	N, tons/ day	DAML, tons (3 mg/l)	DAML, tons (1.5 mg/l)	P, tons/ day	P, 0.08 mg/l	P, 0.05 mg/l	Ndiff, tons (3.0 mg/l)	%	Ndiff, tons (1.5 mg/l)	diff %	Pdiff, tons (0.08 mg/l)	diff %	Pdiff, tons (0.05 mg/l)	diff %
0-10	1437.0	1598.9	799.5	33.95	42.64	31.98	-161.9	-0.11	637.6	0.44	-8.7	-0.26	2.0	-0.11
10-20	659.8	817.3	408.7	12.18	21.80	16.35	-157.6	-0.24	251.1	0.38	-9.6	-0.79	-4.2	-0.42
20-30	367.2	455.7	207.7	7.46	12.15	8.31	-88.5	-0.24	159.5	0.43	-4.7	-0.63	-0.9	-0.03
30-40	322.6	426.0	198.2	5.96	11.36	7.93	-103.3	-0.32	124.5	0.39	-5.4	-0.91	-2.0	0.23
40-50	225.7	311.4	155.7	5.08	8.30	6.23	-85.6	-0.38	70.1	0.31	-3.2	-0.63	-1.1	0.18
50-60	125.8	218.4	105.3	5.60	5.82	4.21	-92.6	-0.74	20.4	0.16	-0.2	-0.04	1.4	0.24
60-70	72.7	138.4	69.2	2.67	3.69	2.77	-65.6	-0.90	3.6	0.05	-1.0	-0.38	-0.1	0.19
70-80	51.6	114.5	55.1	1.34	3.05	2.20	-62.9	-1.22	-3.5	-0.07	-1.7	-1.28	-0.9	0.37
80-90	25.5	72.3	33.3	1.02	1.93	1.33	-46.8	-1.83	-7.8	-0.30	-0.9	-0.89	-0.3	0.20
90-100	12.6	46.3	21.2	0.53	1.23	0.85	-33.7	-2.66	-8.6	-0.68	-0.7	-1.32	-0.3	-0.22

The analysis of N_{tot} and P_{tot} loads over the monitoring period show statistically significant upward trend of nitrates and phosphates and decreasing trend of ammonia since 1993 (Table 16). The PMK test show statistically significant upward trend for total nitrogen and nitrates, indicating possible human impact to upward trend. PO_4-P load showed statistically significant downward trend in 1993-2019, although statistically less significant decreasing trend since 2009.

The long-term (1993-2019) mean daily BFI is 0.61, varying from 0.51 to 0.75, therefore indicating rather high seasonal and annual variability.

Actual fluctuation in nutrient loads has not been well described due to the fact that majority (71%) of the water samples (223 out of 314) collected since 1993 describe only 25% of N load and 29% of P load (Figure 20).

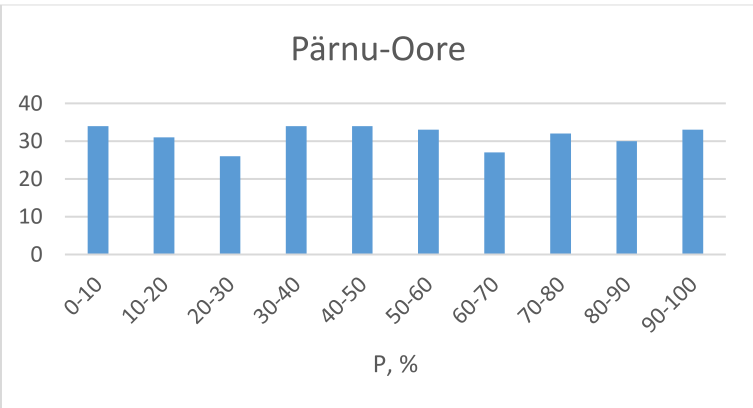


Figure 6.8. Number of water samples during hydrological period.

Navesti-Aesoo

The ecological status of the river Navesti at Aesoo station is fair (Table 4.4.4). The load of P_{tot} show overall compliance with the target, i.e. good status for Ptot. Actual load of N_{tot} show exceedances of the load duration curve during high flow season by 6.6 tons/day (Figure 6.9, Table 6.5). The measured instantaneous load of N_{tot} exceeds the water quality target of very good status by N during most of the seasons reflecting potential impact from nonpoint pollution sources. The sum of exceedances of daily load is at least 190 tons, which should be decreased aiming to achieve very good status by N_{tot}.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during high flow (P=0-10%) by 0.17 tons/day.

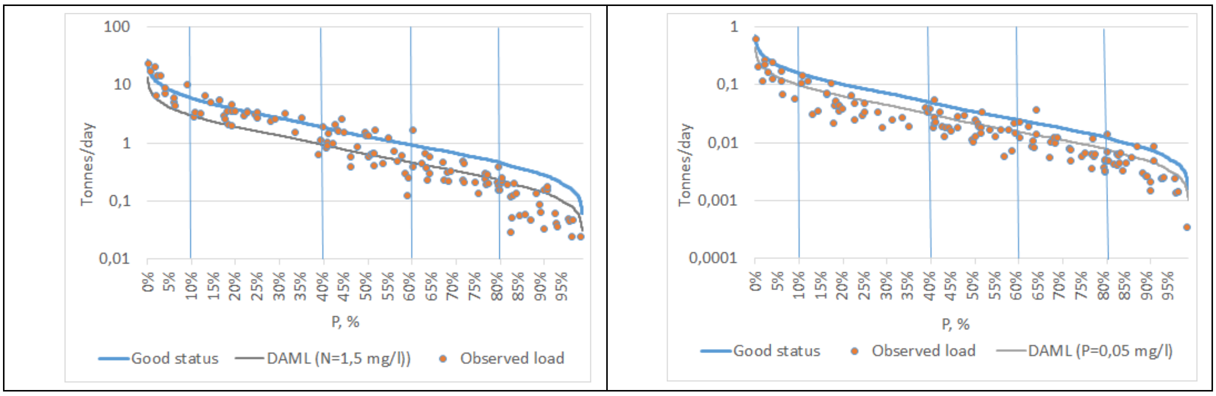


Figure 6.9. Load exceedance probability curves for N_{tot} (left) and P_{tot} (right).

Table 6.5.

Daily load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

Exceedance probability, %	N, tons/ day	DAML, tons (3 mg/l)	DAML, tons (1.5 mg/l)	P, tons / day	P, 0.08 mg/l	P, 0.05 mg/l	Ndiff, tons (3.0 mg/l)	%	Ndiff, tons (1.5 mg/l)	diff %	Pdiff, tons (0.08 mg/l)	diff %	Pdiff, tons (0.05 mg/l)	diff %
0-10	137,7	131,1	65,5	2,35	3,50	2,18	6,6	0,05	72,2	0,52	-1,14	-0,49	0,17	0,07
10-20	53,1	63,6	31,8	0,91	1,69	1,06	-10,4	-0,20	21,3	0,40	-0,78	-0,86	-0,15	-0,16
20-30	27,3	29,4	14,7	0,34	0,78	0,49	-2,0	-0,07	12,6	0,46	-0,44	-1,30	-0,15	-0,44
30-40	9,2	11,0	5,5	0,15	0,29	0,18	-1,8	-0,19	3,7	0,40	-0,15	-1,02	-0,04	-0,26
40-50	20,7	26,1	13,0	0,39	0,70	0,43	-5,4	-0,26	7,7	0,37	-0,31	-0,81	-0,05	-0,13
50-60	11,4	18,1	9,1	0,27	0,48	0,30	-6,7	-0,58	2,4	0,21	-0,22	-0,80	-0,03	-0,13
60-70	6,2	10,3	5,2	0,18	0,28	0,17	-4,2	-0,67	1,0	0,16	-0,09	-0,51	0,01	0,06
70-80	3,2	6,7	3,4	0,08	0,18	0,11	-3,5	-1,12	-0,2	-0,06	-0,10	-1,29	-0,03	-0,43
80-90	2,7	7,4	3,7	0,10	0,20	0,12	-4,6	-1,70	-1,0	-0,35	-0,10	-0,98	-0,02	-0,24
90-100	1,0	3,1	1,6	0,04	0,08	0,05	-2,1	-2,12	-0,6	-0,56	-0,05	-1,28	-0,02	-0,43

The analysis of N_{tot} and P_{tot} loads over the monitoring period show statistically significant upward trend of nitrates and total nitrogen since 1993 (Table 4.4.7), although this increase is statistically less significand since 2009. Statistically significant upward trend for total nitrogen and nitrates according to the PMK test indicate possible human impact to increasing load since 1993. The PMK test showed statitically significant downward trend of PO_4-P load in 1993-2019 that can be explained by decreasing load from point and diffuse sources.

The long-term (1993-2019) mean daily BFI is 0.57, varying from 0.41 to 0.70, therefore indicating rather high seasonal and annual variability.

Actual fluctuation in nutrient loads has not been well described due to the fact that majority (73%) of the water samples (94 out of 129) collected since 1993 describe only 20% of N load and 25% of P load (Figure 6.10.).

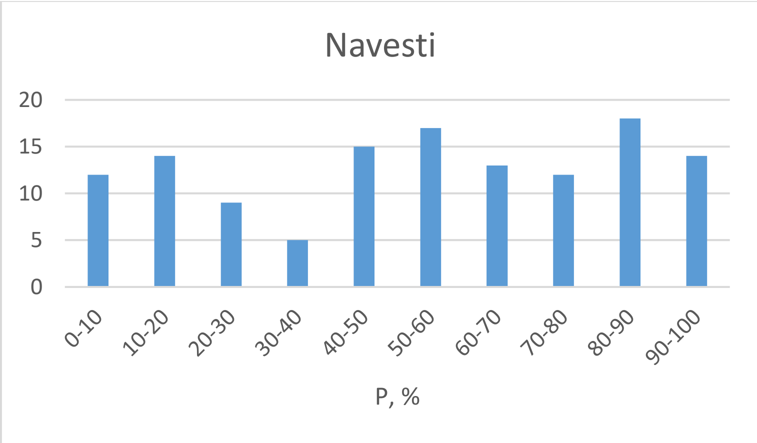


Figure 6.10. Number of water samples during hydrological period.

Halliste-Riisa

The ecological status of the river Halliste is fair in the unpstream part and poor in the downstream part (Table 13). Major reasions for not good status involve damming as well as elevated concentrations of nutrients in some of the defined water bodies. The load of N_{tot} and P_{tot} show overall compliance with the target, i.e. good status for N_{tot} and P_{tot} with few exceedances over different seasons for nitrogen and during dry and low flow season for phosphorus (Figure 6.11., Table 6.6.). The measured instantaneous load of N_{tot} exceeds the water quality target of very good status by N particularly during high flow and wet season reflecting the impact of water flow on N transport. The sum of exceedances of daily load is at least 69 tons, which should be decreased aiming to achieve very good status by N_{tot}.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during low flow and transition zone between dry and wet seasons (P=30-90%) by 0.72 tons/day.

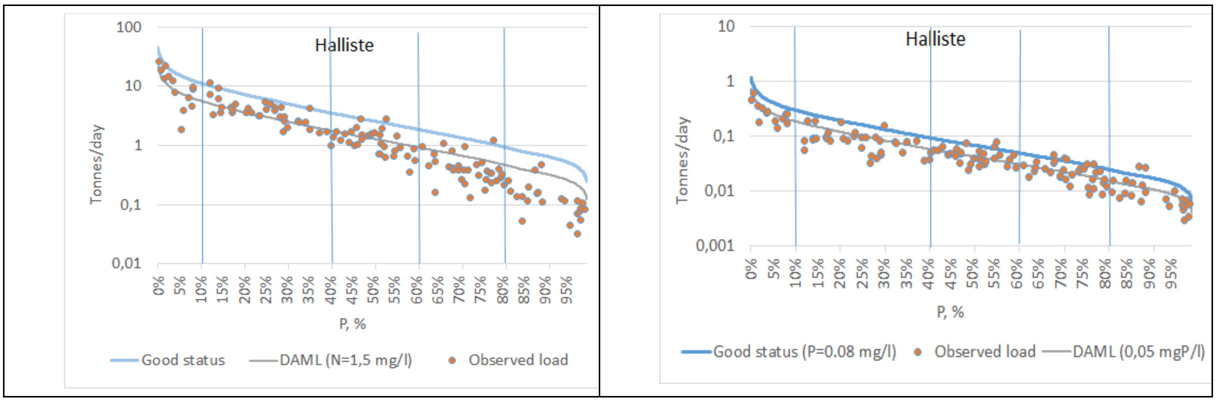


Figure 6.11. Load exceedance probability curves for N_{tot} (left) and P_{tot} (right).

Table 6.6.

Daily load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

Exceedance probability, %	N, tons/ day	DAML, tons (3 mg/l)	DAML, tons (1.5 mg/l)	P, tons/ day	P, 0.08 mg/l	P, 0.05 mg/l	Ndiff, tons (3.0 mg/l)	%	Ndiff, tons (1.5 mg/l)	diff %	Pdiff, tons (0.08 mg/l)	diff %	Pdiff, tons (0.05 mg/l)	diff %
0-10	151,1	247,9	123,9	3,71	6,61	4,13	-96,8	-0,6	27,1	0,2	-2,90	-0,78	-0,42	-0,11
10-20	62,9	99,7	49,9	1,17	2,66	1,66	-36,9	-0,6	13,0	0,2	-1,49	-1,27	-0,49	-0,42
20-30	55,6	89,5	37,7	1,22	2,39	1,26	-34,0	-0,6	17,9	0,3	-1,17	-0,96	-0,04	-0,03
30-40	19,1	34,5	14,7	0,64	0,92	0,49	-15,4	-0,8	4,3	0,2	-0,28	-0,44	0,15	0,23
40-50	23,9	48,1	18,9	0,77	1,28	0,63	-24,2	-1,0	5,1	0,2	-0,51	-0,67	0,14	0,18
50-60	17,8	36,9	15,9	0,70	0,98	0,53	-19,1	-1,1	1,9	0,1	-0,29	-0,41	0,17	0,24
60-70	6,6	17,7	7,9	0,32	0,47	0,26	-11,1	-1,7	-1,3	-0,2	-0,15	-0,46	0,06	0,19
70-80	8,4	24,7	8,3	0,44	0,66	0,28	-16,3	-1,9	0,1	0,0	-0,22	-0,50	0,16	0,37
80-90	2,9	11,1	4,6	0,19	0,30	0,15	-8,2	-2,8	-1,7	-0,6	-0,10	-0,54	0,04	0,20
90-100	0,9	4,7	2,4	0,06	0,13	0,08	-3,8	-4,2	-1,5	-1,6	-0,06	-0,96	-0,01	-0,22

The analysis of N_{tot} and P_{tot} loads over the monitoring period show statistically significant upward trend for nitrogen load and downward trend for phosphorus load since 1993 (Table 4.4.7.). The PMK test revealed even more pronounced trends indicating considerable human impact to the changing pattern of N and P loads until 2009. Both N and P trends are statistically less significant since 2009. The PMK test showed statitically significant downward trend of NH_4-N and BOD_5 load in 1993-2019 that can be explained by decreasing load from point sources.

The long-term (1993-2019) mean daily BFI is quite similar to the river Navesti, i.e. 0.59, varying from 0.43 to 0.73, therefore indicating rather high seasonal and annual variability.

Actual fluctuation in nutrient loads has not been well described due to the fact that majority (71%) of the water samples (94 out of 133) collected since 1993 describe only 23% of N load and 34% of P load (Figure 6.12.).

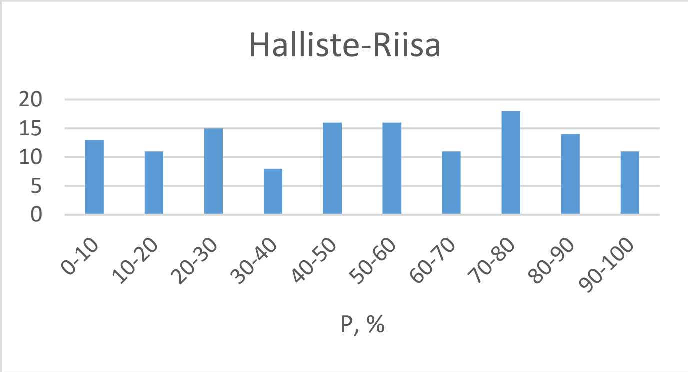


Figure 6.12. Number of water samples during hydrological period.

Vodja-Vodja

The ecological status of the River Vodja is fair or having a fair ecological potential at the heavily modified upstream part of the stream (Table 13). Major pressures involve damming of the river and input of nutrients. The load of P_{tot} show compliance with the target, i.e. good as well as very good status for P_{tot}, except minor exceedance during dry season (Figure 6.13., Table 6.6.). The load of N_{tot} exceeds the target level of good status during high flow period (P= 0-20%) by 1.5 tons/day. The measured instantaneous load of N_{tot} exceeds the water quality target of very good status by N during most of the seasons, particularly during high flow and wet period, reflecting potential impact from nonpoint sources. The sum of exceedances of daily load is nearly 8 tons, which should be decreased aiming to achieve very good status by N_{tot}.

The point sources contribute only 0.8% of the flow-adjusted annual riverine load of N in 2014-2019 but 10% of the load of P (Table 7.2.2.1.). The riverine P load show decreasing trend since 1993. The share of annual mean point source load of total N and P in 2015-2019 in total riverine load during even the dry season (P=90-100%) is rather low, forming only 1,0 and 3,6 %, respectively, indicating considerable input of diffuse P, which is responsible for exceedances of the good status during medium or even high flow periods.

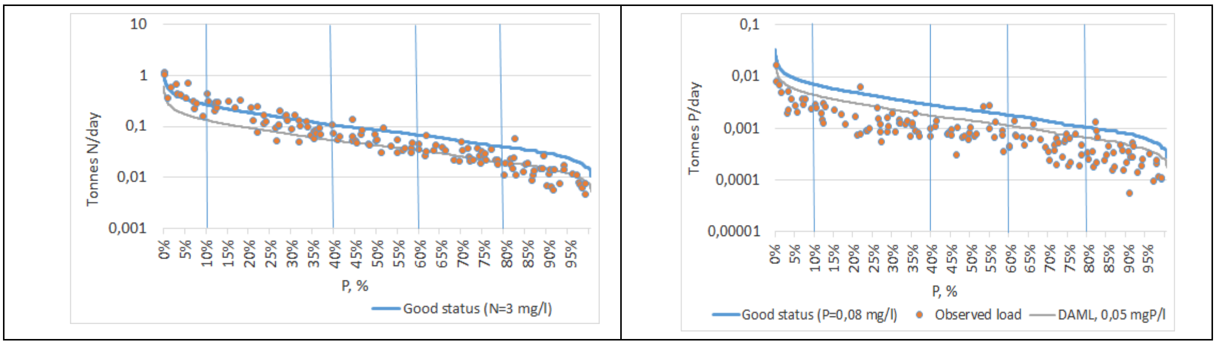


Figure 6.13. Load exceedance probability curves for Ntot (left) and Ptot (right).

Table 6.6.

Daily load exceedance probability during hydrological periods. Red color mark exceedance and green color compliance with DAML.

Exceedance probability, %	N, tons/ day	DAML, tons (3 mg/l)	DAML, tons (1.5 mg/l)	P, tons/ day	P, 0.08 mg/l	P, 0.05 mg/l	Ndiff, tons (3.0 mg/l)	%	Ndiff, tons (1.5 mg/l)	diff %	Pdiff, tons (0.08 mg/l)	diff %	Pdiff, tons (0.05 mg/l)	diff %
0-10	7,1	6,2	3,1	0,07	0,17	0,10	0,92	0,13	4,03	0,56	-0,099	-1,5	-0,036	-0,2
10-20	3,2	2,5	1,3	0,02	0,07	0,04	0,62	0,20	1,89	0,60	-0,045	-2,0	-0,019	-0,3
20-30	1,9	2,4	1,2	0,02	0,06	0,04	-0,43	-0,22	0,76	0,39	-0,040	-1,8	-0,017	-0,3
30-40	1,4	1,8	0,9	0,02	0,05	0,03	-0,44	-0,32	0,47	0,34	-0,032	-1,9	-0,014	-0,3
40-50	0,9	1,3	0,6	0,01	0,03	0,02	-0,40	-0,45	0,25	0,28	-0,023	-1,9	-0,010	-0,3
50-60	0,5	0,9	0,4	0,01	0,02	0,01	-0,37	-0,71	0,07	0,14	-0,011	-0,9	-0,002	-0,1
60-70	0,4	0,6	0,3	0,01	0,02	0,01	-0,22	-0,61	0,07	0,19	-0,009	-1,2	-0,003	-0,2
70-80	0,5	0,8	0,4	0,01	0,02	0,01	-0,36	-0,75	0,06	0,12	-0,014	-1,8	-0,006	-0,3
80-90	0,3	0,5	0,3	0,01	0,01	0,01	-0,25	-0,86	0,02	0,07	-0,008	-1,2	-0,003	-0,2
90-100	0,2	0,4	0,2	0,00	0,01	0,01	-0,22	-1,37	-0,03	-0,18	-0,006	-1,7	-0,003	-0,3

The analysis of nutrient loads since 1993 revealed statistically significant upward trend of N_{tot} and NO_3-N and downward trend of NH_4-N and PO_4-P (Table 4.4.7.). The river discharge did not show any significant trend over this period. Thus, significant trends in nitrogen and phosphorus load can be explained by either increasing or decreasing human induced load of nitrogen and phosphorus compounds to the river. The load of PO_4-P showed statistically significant decreasing trend also during more recent period since 2009. The decreasing trend in loads of other compounds in 2009-2019 is statically less significant, although there was a statistically significant decreasing trend in river runoff. Thus, exceedances of the quality target of very good status can be related to human induced input of nitrogen from diffuse sources.

The long-term (2007-2019) mean daily BFI is 0.77, varying from 0.66 to 0.87, that indicates the importance of groundwater recharge in the Vodja river and rather small seasonal and annual variability in discharge. The river belongs to type B rivers with clear water and low humic content.

Actual fluctuation in nutrient loads has not been well described due to the fact that majority (72%) of the water samples (100 out of 142) collected since 1993 describe only 25% of N load and 37% of P load (Fig. 6.14.).

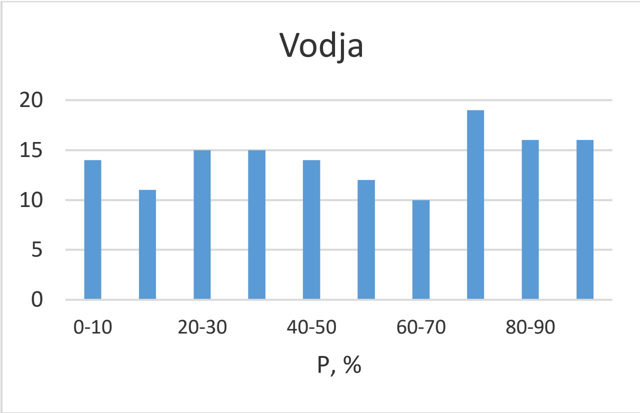


Figure 6.14. Number of water samples during the hydrological period.

7. Assessment of modeled and source apportionment method nutrient source results

7.1. Salaca and Seda river catchment

During 2014-2019, about 970 thous.m3 of wastewater were discharged in surface waters in Salaca River catchment each year. The average TN, NNH4, TP and BOD5 loads were 30.9 t/year, 9.1 t/year, 4.7 t/year and 13.8 t/year, respectively. (Table 7.1.1.). In the Seda River catchment, about 350 thousand. m3 of wastewater were discharged in surface waters each year for the same period. About 14.3 tons of TN, 2.0 tons of NNH4, 1.92 t of TP and 2.1 t of BOD5 was emitted annually in the Seda catchment. In general, higher area-specific wastewater and pollutant loads are observed in Seda catchment (Table 7.1.2.).

Table 7.1.1.

Average wastewater and pollutants load and area-specific load in Salaca and Seda catchments in 2014-2019 (data source: "2-Ūdens").

Parameter	SALACA		Parameter	SEDA	
	average load	area specific load		average load	area specific load
BOD5, t/y	13.8	4.0	BOD5, kg/km2	2.1	3.7
NNH4, t/y	9.1	2.7	NNH4, kg/km2	2.0	3.4
TN, t/y	30.9	9.0	TN, kg/km2	14.3	24.8
TP, t/y	4.7	1.4	TP, kg/km2	1.9	3.3
Flow, thous.m3/y	972	285	Flow, m3/km2	352	612

The share of point source load of N_{tot}, P_{tot} and BOD5 to Salaca River during the extremely low flows (flow exceedance probability 90-100%) is 14.8% for TN, 42.6% for TP and 4.5% for BOD5 assuming that the point source load is evenly distributed over all hydrological periods (Table 7.1.2.). Although this analysis indicates an increasing share from point sources during the low flow periods, it is not possible to estimate the exact share of contribution from point sources due to unknown nutrient retention on the way from discharge site to river mouth. Out of total load from point sources in Salaca catchment, about 50% of TN and 30-50% of TP is discharged by Valka WWTP. This WWTP is discharging in the upper part of the Seda River, which later flows into the Lake Burtnieks. Part of the loads released in upstream areas of the catchment will not reach the monitoring station located at river mouth due to retention processes taking place in streams and lakes.

Table 7.1.2.

Share of TN, TP and BOD5 point source load (tons / month) from total riverine load during hydrological periods (average for period 2015-2019).

P, %	Q, m3/s	TN, t/m	TP, t/m	BOD5, t/m	point TN, t/m	point TP, t/m	point BOD5, t/m	TN, %	TP, %	BOD5, %
0-10	95	685.8	13.9	376.4	2.6	0.39	1.15	0.4	2.8	0.3
10-20	63	348.7	6.5	235.9	2.6	0.39	1.15	0.7	6.0	0.5
20-30	48	252.0	6.0	164.8	2.6	0.39	1.15	1.0	6.5	0.7
30-40	37	208.1	4.3	140.0	2.6	0.39	1.15	1.2	9.1	0.8
40-50	29	147.3	4.1	122.6	2.6	0.39	1.15	1.7	9.4	0.9
50-60	22	79.3	3.2	87.1	2.6	0.39	1.15	3.2	12.3	1.3
60-70	16	53.8	2.7	63.2	2.6	0.39	1.15	4.8	14.3	1.8
70-80	12	35.3	1.8	52.1	2.6	0.39	1.15	7.3	22.0	2.2
80-90	8	24.0	1.2	39.3	2.6	0.39	1.15	10.7	32.7	2.9
90-100	6	17.4	0.9	25.5	2.6	0.39	1.15	14.8	42.6	4.5

Salaca catchment nutrient source apportionment modeling results

The greatest share of nitrogen loads within the catchment originate from forests and arable lands - 46.8 % and 34.5 % respectively. Most important sources of phosphorus load are forest lands and arable lands as well, runoff from forest lands accounts for 36 % of P loads and runoff from arable lands for 30.4 % of the total load in the catchment. Runoff from pasture lands comprises 8,3% of the N load and 6.2 % of P load in the catchment. Major point sources (wastewater treatment plants) – contribute 1.5 % of the nitrogen load and 12.1 % of the phosphorus load.

The graphs below (Figure 7.1.1 and Figure 7.1.2) show nitrogen (N) and phosphorus (P) load distributions by sectors in the Salaca river basin in Latvia for the selected time period (from 2014 to 2019).

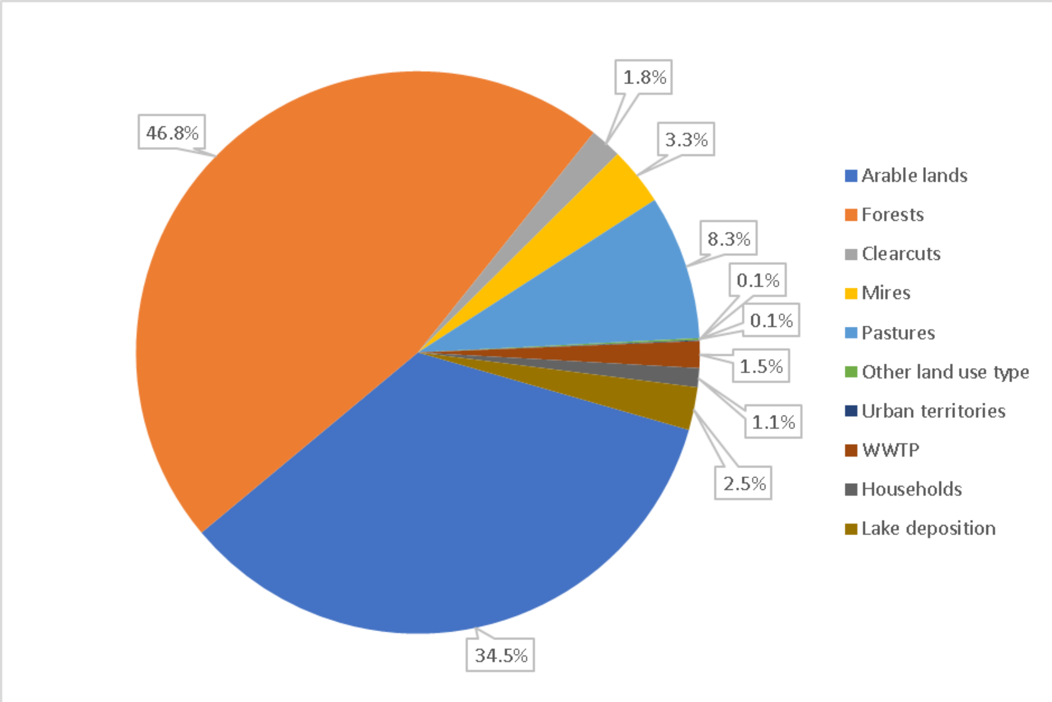


Figure 7.1.1. N source apportionment in Salaca river catchment (2014 – 2019, %).

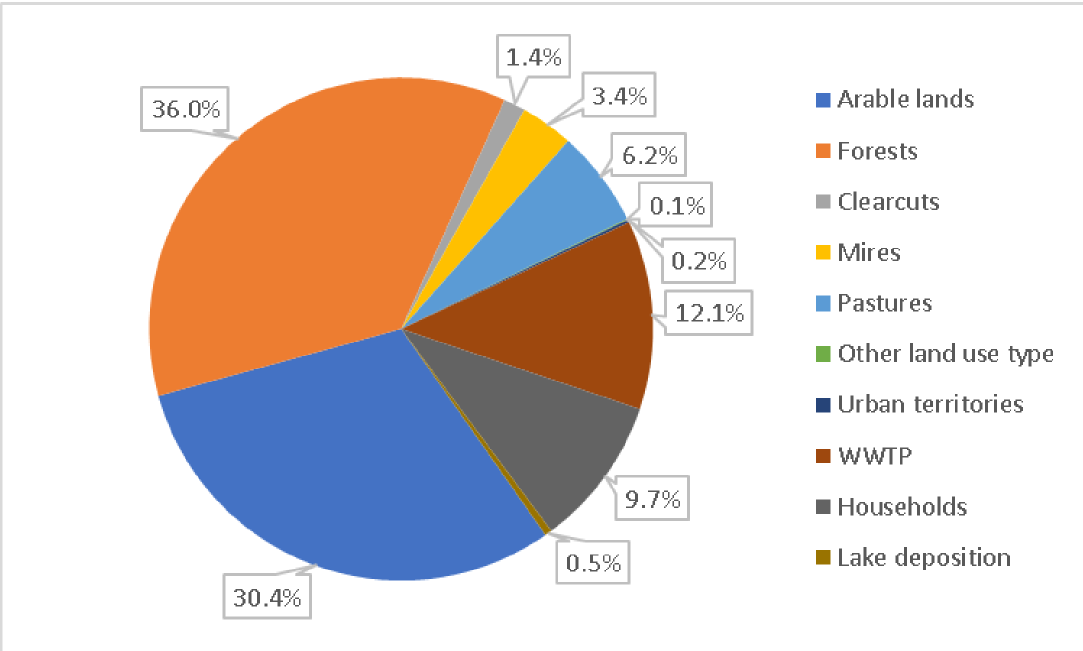


Figure 7.1.2. P source apportionment in Salaca river catchment (2014 – 2019), %.

For most of the waterbodies in the Salaca catchment, the greatest nitrogen load comes from forests or arable lands. The main phosphorus load for several water bodies is WWTP, however, for a large part of Salaca water bodies, as well as for nitrogen load, the main source of load is forests and arable lands. It should be noted that not all arable lands and pastures runoff is considered to be an anthropogenic load, because arable lands and pastures also have a so-called background - natural nitrogen and phosphorus runoff. However, in order to assess the amount of natural (background) load, additional data are needed, for example on the amount of fertilizer applied in the areas or soil types.

Figures 7.1.3. and 7.1.4. show Salaca nutrient source apportionment on a subcatchment scale for years 2014 – 2019.

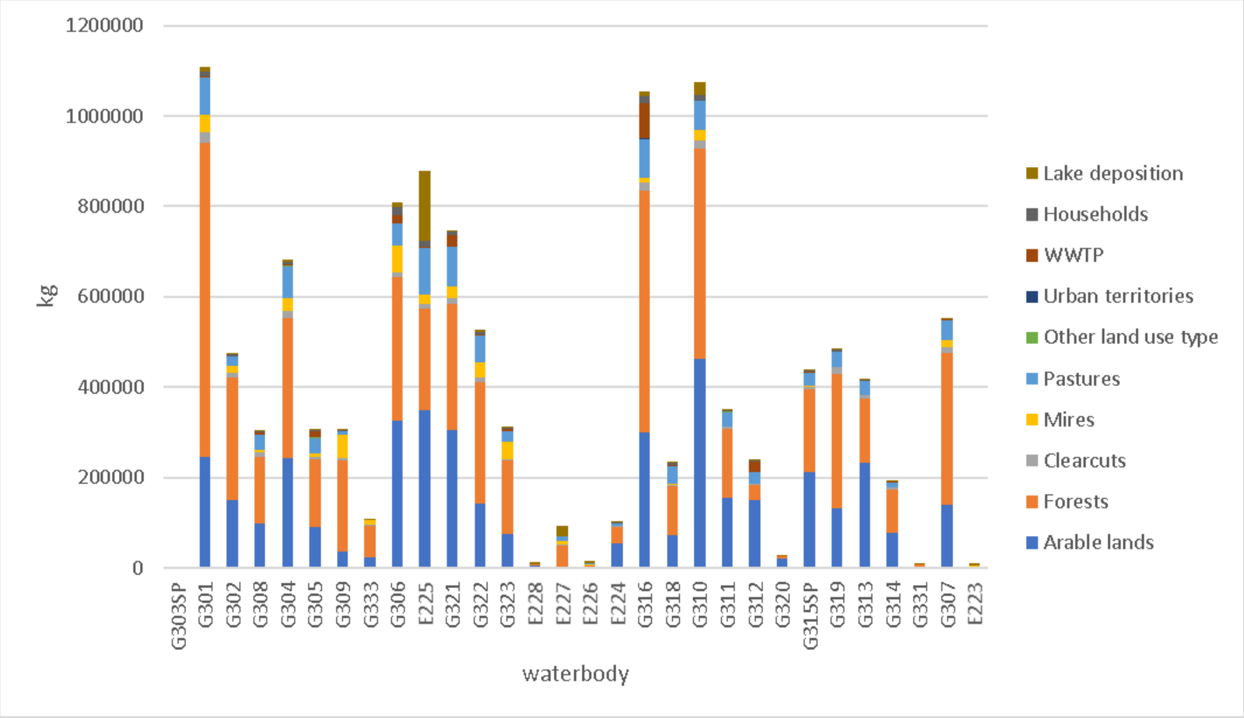


Figure 7.1.3. Salaca N source apportionment on a subcatchment level (2014 – 2019), kg.

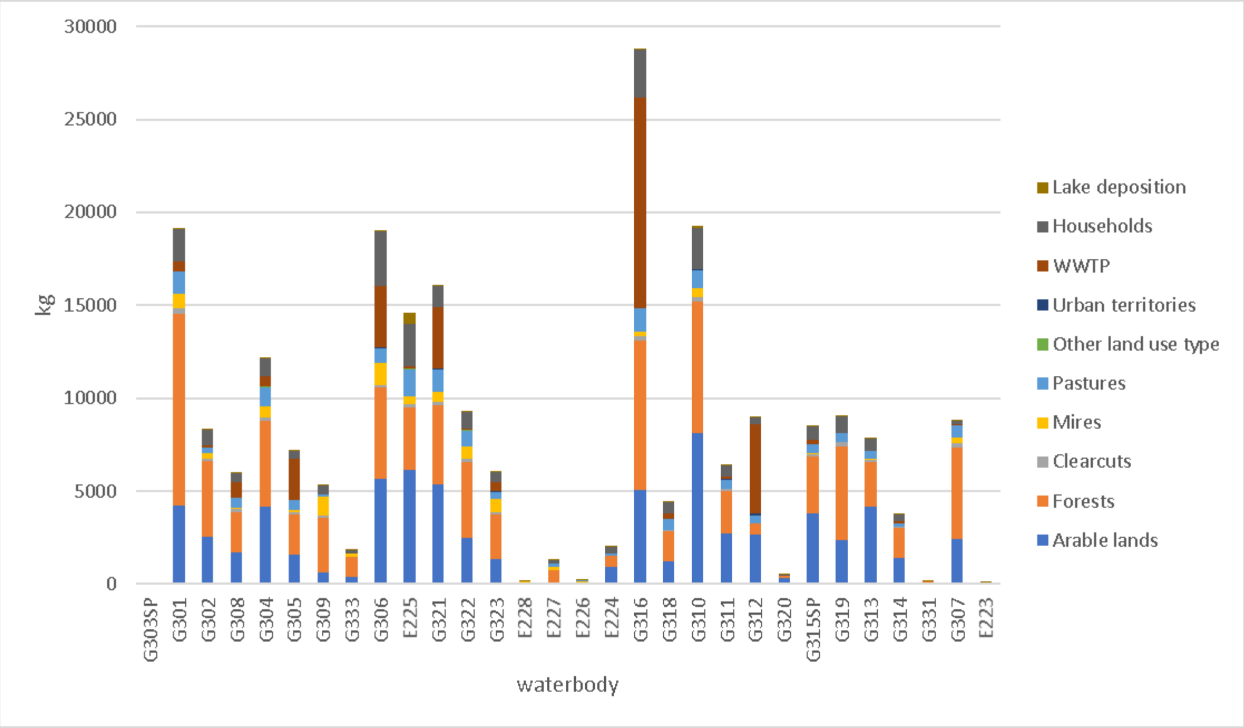


Figure 7.1.4. Salaca P source apportionment on a subcatchment level (2014 – 2019), kg.

7.2. Pärnu river catchment

7.2.1. Point source pollution

Direct discharges of sewage water to the Pärnu bay coastal water body accounted 5,261,545 m^3 in 2019 based on the data by EELIS infosystem. The mean load of N_{tot}, P_{tot} and BOD_7 to the river Pärnu formed 34.8, 2.5 and 28.8 tons, respectively (Table 7.2.1.1.). The rivers Reiu and Sauga received 1.8 and 3.7 tons of N_{tot} and 0.1 and 0.2 tons of P_{tot}. The area specific sewage load of nitrogen to the rivers Pärnu, Reiu and Sauga was 5.0, 2.0 and 6.4 kg/km^2/year, respectively and the load of P_{tot} 2.5, 0.1 and 0.2 kg/km^2/year.

Table 7.2.1.1.

Mean sewage load and area specific load of nutrients BOD_7 and SS in the Pärnu river catchment in 2015-2019 and in 2019 in the Vodja, Navesti and Halliste river catchments (data: National Water Use Database, VEKA).

2014-2019 mean, t/a	Pärnu	incl. Reiu	incl. Sauga	incl. Vodja (2019)	incl. Navesti (2019)	incl. Halliste (2019)
BOD_7	28.8	1.1	6.6	1.0	7.7	4.1
SS	98.3	2.4	21.0	1.3	20.2	10.9
Ntot	34.0	1.8	3.7	0.6	11.2	6.4
Ptot	2.5	0.1	0.2	0.05	0.7	0.4
Kg/km^2/a						
BOD_7	4.2	1.2	11.4	12.5	2.6	2.2
SS	14.4	2.7	36.4	16.3	6.7	5.8
Ntot	5.0	2.0	6.4	7.5	3.7	3.4
Ptot	0.4	0.2	0.4	0.6	0,2	0.2

The share of point source load of N_{tot} and P_{tot} to the rivers during the low flow period (flow exceedance probability 90-100%) varies from 1.0% to 12.2% for N_{tot} and 1.3-9.5% for P_{tot}, assuming that the point source load is evenly distributed over all hydrological periods (Table 7.2.1.2.). Impact of nutrient input by point sources to formation of the water quality is particularly important during low flow period in the river Sauga (12.2% of N_{tot} load and 9.5% of P_{tot} load), being rather high also in the river Navesti (3.1% of N_{tot} load and 5.2% of P_{tot} load).

Table 7.2.1.2.

Share of N_{tot} and P_{tot} point source load (mean for 2015-2019) from total riverine load during hydrological periods.

Exceedance probability, %	Vodja N_{tot}, %	Vodja P_{tot}, %	Pärnu-Oore N_{tot}, %	Pärnu-Oore P_{tot}, %	Navesti N_{tot}, %	Navesti P_{tot}, %	Halliste N_{tot}, %	Halliste P_{tot}, %	Reiu N_{tot}, %	Reiu P_{tot}, %	Sauga N_{tot}, %	Sauga P_{tot}, %
0-10	0.02	0.20	0.01	0.02	0.02	0.08	0.01	0.03	0.01	0.02	0.02	0.04
10-20	0.05	0.60	0.01	0.06	0.06	0.21	0.03	0.09	0.04	0.10	0.27	0.78
20-30	0.08	0.60	0.03	0.09	0.11	0.56	0.03	0.09	0.05	0.14	0.07	0.20
30-40	0.12	0.82	0.03	0.11	0.33	1.32	0.09	0.17	0.06	0.14	0.16	0.37
40-50	0.18	1.16	0.04	0.13	0.16	0.51	0.07	0.14	0.36	0.78	0.42	0.64
50-60	0.32	1.08	0.07	0.12	0.24	0.69	0.10	0.16	0.22	0.40	0.73	1.14
60-70	0.45	1.89	0.13	0.26	0.50	1.05	0.27	0.34	0.47	1.10	0.64	1.47
70-80	0.34	1.69	0.18	0.51	0.97	2.46	0.21	0.25	0.58	0.92	2.38	2.61
80-90	0.56	2.07	0.37	0.67	1.12	1.94	0.60	0.58	1.37	1.63	2.16	2.67
90-100	1.02	3.63	0.74	1.29	3.05	5.23	1.95	1.83	3.79	3.63	12.23	9.54

The sewage load of N_{tot}, P_{tot}, BOD_7 and suspended solids (SS) to the rivers decreased considerably since 1993 (Figure 27), although there has been an increasing trend in the load of SS in the river Sauga over the past 10 years.

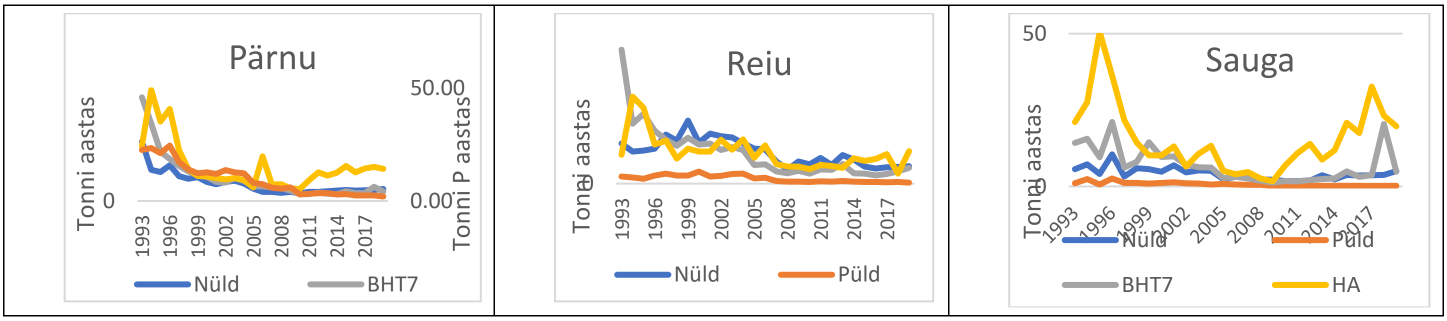


Figure 7.2.1.1. Point source load to the rivers Pärnu, Reiu and Sauga in 1993-2019 (Data: EELIS infosystem).

7.2.2. Diffuse pollution

The results of source apportionment of nitrogen and phosphorus loads in the rivers Pärnu, Sauga and Reiu in 2014-2019 are provided in Table 27. The natural background load has been calculated for forests and wetlands in the catchment upstream of the water quality monitoring stations by applying 25th percentile of concentrations since 1993. Area specific *steady-state* load values 20 and 27 kgN/ha/a ja 0,24 kgP/ha/a from a study by Iital and Loigu (2007) are applied to quantify agriculture-related load from CLC agricultural landcover types.

Retention in the river system is calculated as a difference between the total input load by point and diffuse sources and the measured transport of nutrients at the monitoring station.

The share of natural background load of N_{tot} and P_{tot} varies from 21 to 37% and 44 to 68%, respectively (Table 27). Agriculture contributes 62% to 78% of nitrogen and 31% to 53% of phosphorus. The share of the point source load is 0.4 to 0.7% for nitrogen and 1.8 to 3.5% for phosphorus.

Table 7.2.2.1.

Point and diffuse sources of nitrogen and phosphorous in studied watersheds.

Specific runoff		**Measured load**		**Background load**		**Agricultural load**		**Sewage load**		**Total inner load from point and non-point sources**		**Retention,%**		**Share of pollution sources, %**					
River	l/s/km^2	t/a, 2014-2019 mean		t/a		t/a		t/a, 2015-2019 mean		t/a, 2014-2019 mean				Natural	Agricultural	Sewage	Natura	Agricultural	Sewage
		TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN			TP		
Pärnu	10,0	3807	55,7	1172	31,3	4370	38,0	34,0	2,54	5576	72	32	22	21	78	0,6	44	53	3,5
Sauga	11,0	461	10,1	157	6,5	409	4,8	3,7	0,21	565	12	19	12	28	72	0,7	57	42	1,8
Reiu	12,9	312	6,4	150	5,4	249	2,5	1,8	0,14	401	8	22	20	37	62	0,4	68	31	1,8

8. List of measures for reduction of nutrient loads

Salaca river catchment

30 waterbodies have been divided in the Salaca catchment. According to Gauja River Basin District Management Plan 2022-2027 there are 16 waterbodies in Salaca catchment where some kind of supplementary measures must be implemented to prevent significant pressures and improve the quality of waterbody. In seven of them, the program of measures sets out measures to reduce nutrient loads.

All the measures planned in Gauja river basin management plan 2022-2027 for waterbodies in Salaca river catchment are shown in Annex X.

Measures to prevent agricultural (arable) loads are planned in 6 waterbodies - 4 water bodies to prevent quality deterioration (to reduce N and P loads by 5% of the existing one), 1 water body to reduce P loads directly, and 1 waterbody (for Lake Burtnieku) - to reduce both - N and P (see Table 8.1.).

Table 8.1.

Measures to reduce nutrient run-off from arable lands

Measure	Rūja		Rūja		Ķire		Acupīte_2		Burtnieku ezers		Lielais Bauzis		kg per year in total when implementing	
	G310		G313		G315SP		G320		E225		E228			
	N, kg per year	*P, kg per year*	*N, kg per year*	*P, kg per year*	*N, kg per year*	*P, kg per year*	*N, kg per year*	*P, kg per year*	*N, kg per year*	*P, kg per year*	*N, kg per year*	*P, kg per year*	*N, kg per year*	*P, kg per year*
Establishment of perennieal plantations on arable land	730.0	12.6	344.1	6.0	281.8	4.9	30.4	0.5	596.9	10.3		0.1	1983.3	34.4
Minimal tillage	1946.7	33.3	917.7	15.8	751.6	13.0	81.0	1.4	1591.7	27.2		0.3	5288.7	91.1
Reduction in the use of nitrogen fertilizers (20% of normal)	567.8		267.7		219.2		23.6		1910.1				2988.4	0.0
Sedimentation pond (basin)									612.0			0.5	612.0	0.5
Controlled drainage									5439.1				5439.1	0.0
Artificial wetland (surface/groundwater)									6302.5				6302.5	0.0
Total reduction, kg per year	**3244.5**	**45.9**	**1529.5**	**21.8**	**1252.6**	**17.9**	**135.0**	**1.9**	**16452.3**	**37.5**	**0.0**	**1.0**	**22613.9**	**126.1**

The measures to reduce the load from forestry (diffuse pollution) are planned only in 1 waterbody to reduce the P load (see table 8.2).

Table 8.2.

Measures to reduce nutrient run-off from land used for forestry

Measure	Jogla	
	G308	
	N, kg per year	*P, kg per year*
Sedimentation pond (basin)		6.0

The measure to reduce the load generated by WWTPs (point source pollution) is planned in only 1 waterbody (to reduce the P load) (see table 8.3.).

Table 8.3.

Measures to reduce nutrient pressure from WWTPs

Measure	Jogla	
	G308	
	N, kg per year	*P, kg per year*
Improve the performance of wastewater treatment plants		58.8

By implementing all the planned measures to reduce nutrient loads, it is expected that the possible achievable reduction of N will be 22614 kg per year, P - 191 kg per year.

It should be noted that the Gauja river basin management plan provides an exemption status for certain water bodies, as it is expected that the water body will not achieve good water quality by 2027.

It is expected that the four water bodies from those where measures to reduce nutrient loads have been set will not achieve good water quality by 2027 (Burtnieku ezers E225, Rūja G310, Rūja_2 G313, Acupīte_2 G320) due to natural conditions (WFD Article 4(4)), which means that it will take time for the effects of the measures introduced to be reflected in the improvement in water quality.

Pärnu river catchment

Needed measures in the Pärnu river catchment starting from the upstream tributaries of the river.

The watershed management plans propose a list of measures to reduce the load of nutrients from point and non-point sources and to achieve at least good status of water bodies (https://www.envir.ee/sites/default/files/laane-eesti_vesikonna_veemajanduskava_2.pdf). The water regime of rivers in Latvia and Estonia is characterized by large annual and seasonal variation in discharge that largely define the formation the water quality, the load of nutrients and the share of diffuse and point pollution in total riverine load.

Therefore, it is utmost important to understand what are the measures that contribute the most in achieving the goal during different hydrological seasons. The DAML methodology provide some input for the assessment, although more specific list of measures requires additional catchment and field scale studies. Most of the efficient measures to reduce the diffuse agricultural load should be applied on farm and field scale and require rather precise land-use data over many years.

Vodja

Exceedances of N load during most of the seasons in the river Vodja, that is the upstream tributary of the river Pärnu, and high BFI indicates the importance of groundwater in formation the water quality and relatively high content of nitrates and Ntot in the stream. The area specific flow-adjusted mean annual load of nitrogen in the catchment is very high (15 kg/ha/a) that can be explained by the high share of agricultural land area in the catchment

(59%) considering good relationships (R^2=0.8) between the share of agricultural land in studied catchments and the area-specific load of nitrogen. Therefore, measures to control diffuse load are needed both in the river catchment as well for the upstream groundwater bodies in the NVZ. Suitable measures to decrease the N load during low flow period involve increased retention time by applying sedimentation ponds, controlled drainage, etc. Reduction of the load of N during high flow periods could be achieved by proper implementation of the requirements set by the Water Act that contribute to lowering of N concentrations.

The share of point source load of P in total riverine load is rather low even during the dry season (P=90-100%), indicating considerable input of diffuse P, which is responsible for exceedance of the good status during medium or even high flow periods. Therefore, the required measures to control P load are similar to those for nitrogen.

Pärnu-Türi and Pärnu-Tahkuse

The water quality and nutrient load at Pärnu-Türi and Pärnu-Tahkuse stations is largely impacted by the upstream tributaries that collect the water from the karstic lime- and dolostone plateau. Rater high N content at Pärnu-Türi station reflect the potential impact from non-point and point pollution sources, which could be decreased by applying agri-environmental measures to increase the retention time during the low and medium flow periods. The concentration of nitrogen decreases downstream to the Pärnu-Tahkuse station where the mean area-specific load of N is nearly two times lower compared to the upstream Vodja station. The load during high flow periods could only be controlled by proper implementation of the requirements set by the Water Act that contribute to lowering on N concentrations in upstream tributaries of the river.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during high flow and wet season as well as during the transition zone between moist and wet indicating the role of agricultural diffuse load as well as point source load during the transition period. The needed measures should, therefore, involve proper implementation of the requirements set by the Water Act that contribute to lowering on P concentrations in upstream tributaries of the river. It involves improved removal of point source load of P considering rather high share of artificial areas in the landcover (1.7%) of the Pärnu-Tahkuse catchment.

Halliste

The geological features, e.g. sandstone, aleurite and clay in southern part of the river Pärnu catchment area largely determine the formation of the water quality in the rivers Halliste and Navesti. The share of groundwater recharge in river water is only 25 and 28% and the mean BFI is 0.59 and 0.57, respectively.

The load of N_{tot} and P_{tot} in the river Halliste show overall compliance with the target, i.e. good status for N_{tot} and P_{tot} with few exceedances over different seasons for nitrogen and during dry and low flow season for phosphorus. The measured instantaneous load of N_{tot}

exceeds the water quality target of very good status by N particularly during high flow and wet season reflecting the impact of water flow on N transport. The needed measures to reduce the load of N during high flow periods involve proper implementation of agri-environmental measures and requirements set by the Water Act that contribute to lowering on N concentrations and diffuse load, although the share of agricultural land in the river catchment is rather low (34%) compared to upstream tributaries of the river Pärnu.

The measured instantaneous load of P_{tot} at the river Halliste-Riisa station exceeds the water quality target of a very good status by P during low flow and transition zone between dry and wet seasons indicating possible impact of point source load. The share of artificial landcover types in the catchment upstream of the Halliste-Riisa station is rather high (1.5%). The mean share of P_{tot} point source load from the total riverine load is higher during the dry season when it forms about 1.8% of the loads that should be reduced to some extent to minimize exceedances of the P load curve.

Navesti

The load of N_{tot} exceeds the water quality target of good status by N in the river Navesti during high flow season and of a very good status during most of the seasons, except the low flow period reflecting potential impact from nonpoint pollution sources. Suitable measures to decrease the N load during the transition zone between moist and wet involve increased water retention time in the tributaries and drainage systems in the catchment. The needed measures to reduce the load of N during high flow periods involve proper implementation of agri-environmental measures and requirements set by the Water Act that contribute to lowering of N concentrations.

The load of N is in agreement with the water quality target of good status during low flow period (P=80-100%) despite of the considerable input by point source N during the low flow period.

The load of P_{tot} show overall compliance with the good status target for Ptot but exceeds the water quality target of a very good status by P during high flow period and the transition zone between moist and wet. Therefore, suitable measures include increasing of the water retention time in tributaries and drainage systems in the catchment.

The water quality target of a very good status for P is achieved during the dry period (P=90-100%), although the share of point source load of P form more than 5% of the total load during this period.

Pärnu-Oore

The load of N_{tot} and P_{tot} show overall compliance with the target, i.e. good status for N_{tot} and P_{tot}, although several exceedances of the load duration curve occur during high flow and wet seasons, as well as during the transition period for P_{tot}. The measured instantaneous load of N_{tot} exceeds the water quality target of a very good status by N during most of the seasons reflecting potential impact from nonpoint pollution sources. The needed measures to reduce the load of N during high flow periods involve proper implementation of agri-environmental measures and requirements set by the Water Act that contribute to lowering of N concentrations.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during the high flow season (P=0-10%), as well as the transition zone between moist and wet (P=50-60%) indicating contribution of diffuse load. Therefore, suitable measures include increasing of the water retention time in tributaries and drainage systems in the catchment.

Reiu

The load of N_{tot} and P_{tot} show compliance with the target, i.e. good status for N_{tot} and very good status for P_{tot}. The measured instantaneous load of Ntot exceeds the water quality target of very good status by N during high flow period with the flow exceedance probability 0-30%, reflecting potential impact from nonpoint sources, including natural background load. The share of forests and wetlands in the land cover of the catchment is 80% and the river water is dark colored and humic-rich. The load N to the stream from wetlands is probably remarkable although specific data to confirm it is missing. The area specific riverine load of N from the catchment is lower compared to other studied sub-catchments of the river Pärnu. The trend analysis did not reveal any statistically significant trends in N load since 1993. The share of calculated agricultural load of N is still rather high due to the fact that most of the agricultural land can be found in the vicinity of the main stream in the middle and downstream parts of the river catchment. The list of measures to reduce the load of N during high flow periods is, therefore, rather limited and involve proper implementation of agri-environmental measures and requirements set by the Water Act as well as measures to control N load from drained peatlands and peaty forests.

The point sources contribute only 0.7% and 1.8% of the total load of N and P, but up to 3.8 and 3.6 %% of the total N and P load during the dry season (P=90-100%), respectively. Minimization of possible exceedances of P load require, therefore, implementation of technical measures to reduce the sewage load.

Sauga

The load of N_{tot} and P_{tot} show compliance with the target, i.e. good status for N_{tot} and P_{tot}, except minor exceedance during the wet season for N_{tot} (P=10-20%). The measured instantaneous load of N_{tot} exceeds the water quality target of a very good status by N during most of the seasons, particularly during high flow period with the flow exceedance probability 0-10%, reflecting potential impact from nonpoint sources, e.g. agricultural land and drained peatlands in the upstream of the river. Therefore, the needed measures to reduce the load of N during high flow periods involve proper implementation of agri-environmental measures and requirements set by the Water Act as well as that contribute to lowering of N concentrations measures to reduce N load from drained peatlands and peaty forests in upstream part of the catchment.

The measured instantaneous load of P_{tot} exceeds the water quality target of a very good status by P during high flow and wet season (P=0-20%), as well as the low flow and dry season (P=60-90%). The point sources contribute only 0.8% and 3.7% of the total riverine load of N and P respectively, but about 12% and 10 % of the total N and P load during the dry season (P=90-100%), respectively. Reduction of possible exceedances of P load during low-flow period require, therefore, implementation of technical measures to reduce the sewage load.

Conclusions

- Most of the applied measures to achieve good status of water bodies by nutrients and to reduce the riverine load of nitrogen and phosphorus does not properly account for seasonal variation in discharge.
- Application of the tested DAML methodology provides an efficient tool to assess seasonal exceedances of nutrient loads and for the selection and justification of temporarily efficient catchment scale measures to reduce the riverine load of nutrient to the Gulf of Riga and the Baltic Sea.
- Most of the exceedances of the maximum daily loads to achieve at least good status by nitrogen and phosphorus in studied river catchments are detected during the high flow periods indicating the importance of the diffuse load that is largely impacted by water discharge.
- More exceedances are detected in upstream sub-catchments of the Pärnu and Salaca rivers that are quite heavily impacted by intensive agriculture as well as by point source pollution.
- Therefore, suitable measures to minimize exceedances of the target daily flows include increasing of the water retention time in tributaries and drainage systems in the catchment during dry season and the transition period between moist and wet as well as proper implementation of agri-environmental measures and requirements set by the law that contribute to lowering of concentrations, particularly during the high-flow/wet season.
- Natural background load of nutrients from forests and wetlands form quite a considerable portion of the total riverine load of nitrogen and phosphorus in studied streams. Therefore, increasing of the water retention time in tributaries and drainage systems of forest and wetlands could contribute to reducing exceedances of daily N and P loads during the low flow and transition period.
- Defining of the more specific list of measures to reduce transport of nutrients to the Gulf of Riga and the Baltic Sea and achieving at least of good status of the rivers over all seasons and the coastal sea require additional catchment and field scale studies. Most of the efficient measures to reduce the diffuse agricultural load should be applied on farm and field scale and require rather precise land-use data over many years.

References

AS Entec/Dereevos OÜ, 2002. Pärnu alamvesikonna veemajanduskava, 174 p.

CLC, 2018. Corine Land Cover. Copernicus - European Union's Earth observation programme. https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

Daughney, C.J., (2010) Spread Sheet for Automatic Processing of Water Quality Data: 2010 Update, Calculation of Percentiles and Tests for Seasonality. GNS Science Report 2010/42. GNS Science, Lower Hutt, 16 p.

Decree of the Minister of the Environment, 2020. Keskkonnaministri 24.04.2020. a määrus nr. 19 „Pinnaveekogumite nimekiri, pinnaveekogumite ja territoriaalmere seisundiklasside määramise kord, pinnaveekogumite ökoloogiliste seisundiklasside kvaliteedinäitajate väärtused ja pinnaveekogumiga hõlmamata veekogude kvaliteedinäitajate väärtused"

Envirotech, 2020. GIS Latvija 10.2 geodatabase. https://www.gisbaltic.eu/lv-lv/home

EPA, 1991. Guidance for Water Quality-based Decisions: The TMDL Process. U.S. Environmental Protection Agency. Office of Water. EPA 440/4-91-001, 59pp.

EPA, 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. Office of Wetlands, Oceans and Watersheds, U.S. Environmental Protection Agency, EPA 841-B-07-006, 69p.

Geological map of Latvia Scale 1:200 000 (explanatory note and maps), 2002. Latvian Statte Geological Survey.

Grīnfelde, I., Bērziņa, L., et.al. 2019. GURINIMAS Integrated nitrogen management system for Gulf of Riga. Project GURINIMAS.

Gustard, A., Bullock, A., Dixon, J. M., 1992. Low flow estimation in the United Kingdom. Wallingford, Institute of Hydrology, 88 pp. (IH Report No.108).

Hansson, K., Wallin, M., Djodjic, F., Orback, C. 2008. The *FyrisNP* model Version 3.1 – A tool for catchment-scale modelling of source apportioned gross and net transport of nitrogen and phosphorus in rivers. A user´s manual. Institutionen för miljöanalys, SLU.

HELCOM (2018a) Sources and pathways of nutrients to the Baltic Sea. Baltic Sea Environment Proceedings No. 153.

HELCOM (2018b) HELCOM Thematic assessment of eutrophication 2011-2016. Baltic Sea Environment Proceedings No. 156

Hirsch R.M., Slack, J.R. (1984) A nonparametric trend test for seasonal data with serial dependence. Water Resources Research 20: 727-732.

Iital A., Loigu E., 2020. Development, testing and promotion of novel methodology for Estimation of Daily Allowable Maximum Loads (DAML) of pollutants to decrease nutrient load to the Gulf of Riga. Methodology. TTU, Tallin.

Iital ja Loigu 2007. Hajureostuse koormuse andmete täpsustamine. Report (in Estonian), Tallinn University of Technology, 19 p.Keskkonnaministri 24.04.2020. a määrus nr. 19

Kļaviņš, M., Rodinov, V., Kokorīte, I., Kļaviņa, I., Apsīte, E. (2001) Long-term and seasonal changes in chemical composition of surface waters in Latvia. *Environmental monitoring and assessment*, *66*(3): 233-251.

LAD, 2018. Rural Support Service Republic of Latvia. LAD Lauki, geodatabase.

LĢIA, 2019. Digitālā augstuma modeļa pamatdati. https://www.lgia.gov.lv/lv/Digit%C4%81lais%20virsmas%20modelis

Libiseller, C., Grimvall, A. (2002) Performance of partial Mann–Kendall tests for trend detection in the presence of covariates. Environmetrics: The official journal of the International Environmetrics Society 13: 71-84. https://doi.org/10.1002/env.507

Martin, 2017. Rannikumere ülevaateseire 2016. Aruanne. Leping: 4-1/16/58, TÜ Eesti Mereinstituut.

PUMA model of the Baltic Artesian Basin results, https://www.puma.lu.lv/dati/

Stigebrant, A., Wulff, F. 1987. A model for the dynamics of nutrients and oxygen in the Baltic proper. Journal of Marine Research 45: 729–759.

Thalfeldt, M., 2013. ESTONIAN RIVERS HYDROCHEMICAL MONITORING STATIONS CATCHMENT AREAS LAND COVER AND CROPS. Master thesis at TalTech, 108 p.

Water Framework Directive, 2000. "Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

Annex

Annex 1.

All the measures planned in Gauja river basin management plan 2022-2027 for waterbodies in Salaca river catchment.

Code	Measure	Burtnieku ezers	Dauguļu Mazezers	Lielais Baužis	Salaca_2	Salaca	Īģe_1	Salaca_1	Jogla	Rūja	Rūja_3	Rūja_2	Ķire	Seda	Acupīte_2	Briede_2	Briede_1	Number of WB where measure planned
		E225	E226	E228	G301	G303SP	G304	G306	G308	G310	G313	G313	G315SP	G316	G320	G321	G322	
A1.2.	To improve the operation of WWTP in order to meet the requirements for achieving the quality objective of the water body, in accordance with the changes made by the SES in the permit for polluting activities as a result of the implementation of the measure A8.1.								x									**1**
A2.1.	To establish perennial plantations on arable land	x		x						x	x		x		x			**6**
A2.2.	Introduce conservative (minimal) tillage	x		x						x	x		x		x			**6**
A2.3.	Reduce the use of nitrogen fertilizers (by 20% of the norm)	x								x	x		x		x			**5**
A2.4.	Create a sedimentation ponds (basins)	x		x						x	x		x		x			**6**
A2.5.	Install controlled drainage	x																**1**
A2.6.	Install artificial wetlands (surface or underground)	x																**1**
A2.7.	Switch to organic farming	x																**1**
A2.8.	Install a 6 m wide buffer zone along watercourses (drainage ditches)	x		x														**2**
A3.4.	Create a sedimentation ponds (basins)								x									**1**
A5.1.	Ensure ecological flow in accordance with the changes made inthe permits for the use of water resources according to results of measure A8.2.																x	**1**
A5.4.	To build a fish road to HPP dams and other dams				x												x	**2**
A5.5.	To ensure the lateral continuity of the river - to restore the naturalness of the river bed				x		x		x	x	x	x	x		x		x	**9**
A5.6.	Monitor the effect of measure A5.4.										x	x	x		x			**4**
A5.8.	Demolish the dam to ensure the longitudinal continuity of the river				x				x		x	x					x	**5**
A6.10.	Biomanipulation in the lake	x																**1**
A7.1.	Identify sources of heptachlor, heptachlor epoxide and / or mercury and implement measures to reduce its pollution: A7.1.1. Monitor heptachlor, heptachlor epoxide, mercury in surface water and / or precipitation water; A7.1.2. Perform data analysis to determine the source of pollution; A7.1.3. Implement measures to reduce pollution.	x			x													**2**
A7.2.	Monitor fluoranthene and / or anthracene in effluents and / or surface water	x																**1**
A7.5.	To carry out enhanced control over the efficiency of WWTP operation and preparation of proposals for the improvement of WWTP operation, if the need for improvement of WWTP operation is identified during the control							x						x		x		**3**
A7.7.	Carry out research on the sources of nutrient loads and their effects, as well as prepare proposals for the prevention of loads	x		x														**2**
A7.8.	Operational and trend monitoring in the fish matrix for chemical quality control	x	x			x												**3**
A8.1.	To review the polluting activity permits issued to WWTP operators, to make changes in the permitted discharges of polluting substances								x									**1**
A8.2.	To determine appropriate ecological flow requirements, to make changes in the water resources use permit issued by the HPP																x	**1**
	The number of measures planned in WB	**13**	**1**	**5**	**4**	**1**	**1**	**1**	**5**	**5**	**7**	**3**	**6**	**1**	**6**	**1**	**5**	**65**