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Input of nutrients by
The seven biggest rivers in the Baltic Sea region
in 1995–2017

Baltic Marine Environment
Protection Commission

Nutrient inputs

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Summary

Figure 1. The catchment areas of the seven biggest rivers of the Baltic Sea catchment.

The seven biggest rivers cover half of the Baltic Sea catchment area. Nearly 55 million people inhabit their catchment areas, meaning that anthropogenic pressure is high. Anthropogenic pressure is highest in the southern catchments, where population is densest and agricultural activity is intense. Consequently, the nutrient loads are high in the south: For example, in 2017 the area specific total nitrogen load of the River Nemunas was 838 kg km-2, whereas it was 133 kg km-2 for the River Kemijoki (in the north). The variation in the area specific total phosphorus loads was in 2017: The River Göta älv 4.3 kg km-2 and the River Nemunas 26 kg km-2. The seven rivers exported 372,000 t of total nitrogen and 13,500 t of total phosphorus into the Baltic Sea in 2017, which was nearly 40% of the total nitrogen and phosphorus loads of the Baltic Sea. The Neva River contributed over 40% of the total flow into the Baltic Sea Catchment area, but the River Vistula had the highest total nitrogen and total phosphorus loads in 2017 with 30% and 28% respectively. Total phosphorus load showed a statistically significant decrease from 1995 to 2017, with total phosphorus being decreased by 6,000 t (30%), but the trends for individual rivers varied greatly. The decreasing tendency in the total nitrogen load found previously had levelled off. To enable division of nutrient load reductions according to their origin country nutrient input ceilings were established for five of the seven biggest rivers (the 5 biggest transboundary rivers). In 2017 the remaining reduction to fulfill the input ceiling of those five rivers was 71,000 t of total nitrogen and 8600 t of total phosphorus. The proportion of the remaining TN reduction of the five biggest rivers was 56% of the total remaining TN reduction of the whole Baltic Sea and 88% of the remaining TP reduction respectively.

1. Introduction

Nearly 55 million people live in the catchment of the seven largest rivers entering the Baltic Sea. The human pressure is highest in southern parts of the catchment, where population is densest and agriculture most intensive (Table 1, Figure 2). Around half of the catchment areas of the Nemunas, Vistula and Oder rivers are covered by agricultural areas, whereas forests dominate the catchments of the Göta älv, Kemi, Neva and Daugava rivers. The proportion of inland lakes is high (>15%) in the Göta älv and Neva River catchments, which substantially reduces pollution load exported by those rivers.

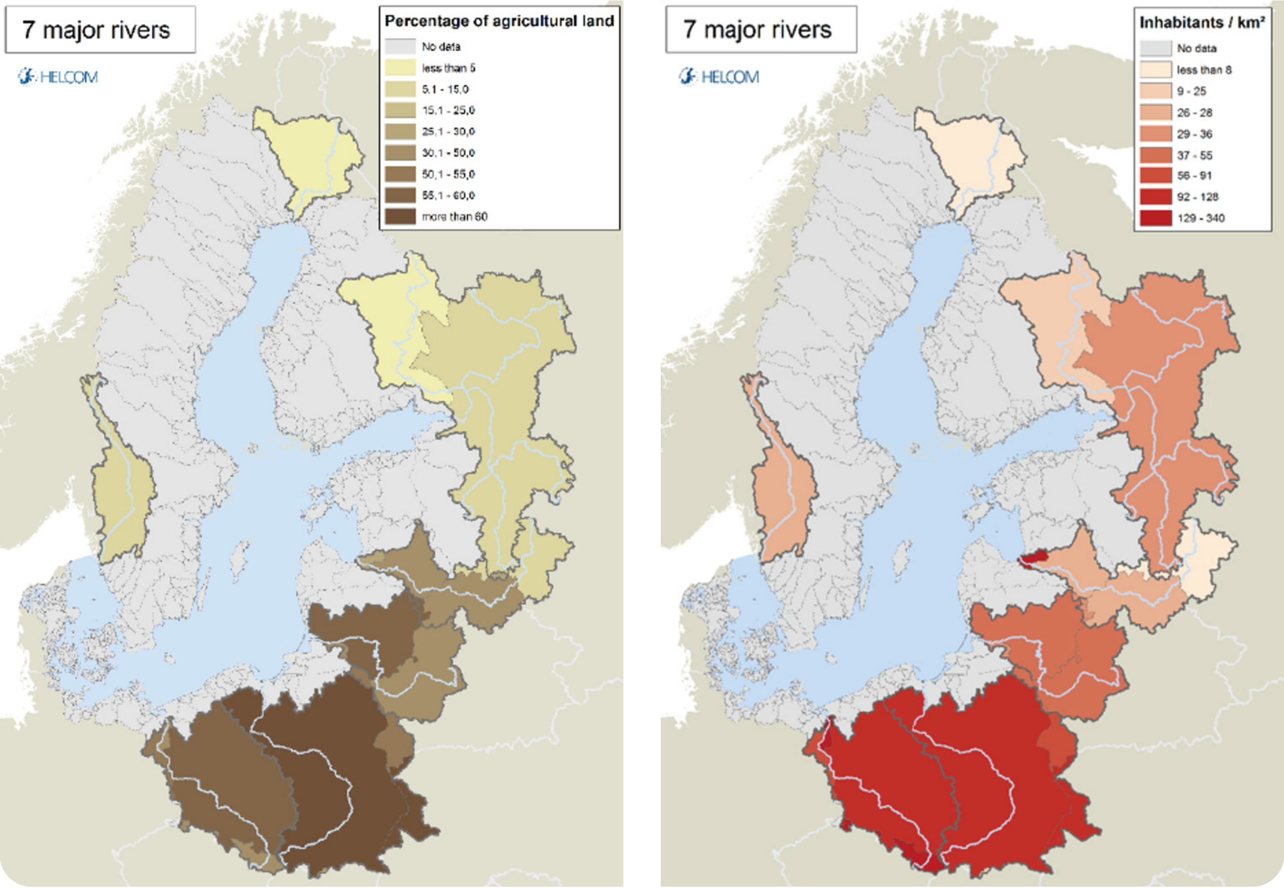


Figure 2. Distribution of agricultural land (2012 for all countries except Russia, where the data is from 2005) and population density in the catchments or sub-catchments of the seven biggest rivers (2012).

Table 1. Catchment characteristics of the seven biggest rivers and the entire Baltic Sea.

River	Area (km^2)	Length (km)	Population	Population density (people per km^2)	Cultivated area (%)	Urban/ paved area (%)	Forest (%)	Inland waters (%)	Other areas (%)
Gota	50 200	756	1 030 000	21	9	0.7	63	18	9
Kemi	51 100	500	10 2000	2	1	0.7	75	5	18
Dauguva*	87 900	1020	2 783 000	32	20	0.4	52	2	26
Nemunas*	97 900	937	4 890 000	50	49	0.8	30	1	19
Oder*	118 015	854	14 480 000	123	48	2	34	1	15
Vistula*	183 176	1047	2 080 000	114	49	1	31	1	18
Neva	281 600	74	6 108 000	22	12	0.1	55	17	16
Big 7 Total	869 891		50 193 000	58	29	0.7	46	7	17
Whole Baltic Sea	1 729 500		84 000 000	49	25	3	53	8	10

2. All seven rivers:

Loads in 2017 and trends between 1995 – 2017

The area specific total nitrogen and total phosphorus loads of the seven biggest rivers vary widely, with a general increasing trend from north to south, as population density increases (Figure 3). On the contrary, runoff values are highest in the northernmost basin (the River Kemijoki), where evaporation is low (Table 2). The highest area specific nutrient loads were detected in the Vistula river basins (Table 2), but some sub-catchments of the Daugava and Nemunas rivers were characterized by equally high values of area specific total nitrogen loads (Figure 3). However, the average specific load from the whole river basins were distinctly lower than in the Vistula. The area specific total phosphorus loads were the highest in the Vistula River basin, and the lowest area specific loads were reported for the relatively pristine Kemi River basin and the upstream sub-catchments of the Neva basin (Figure 3).

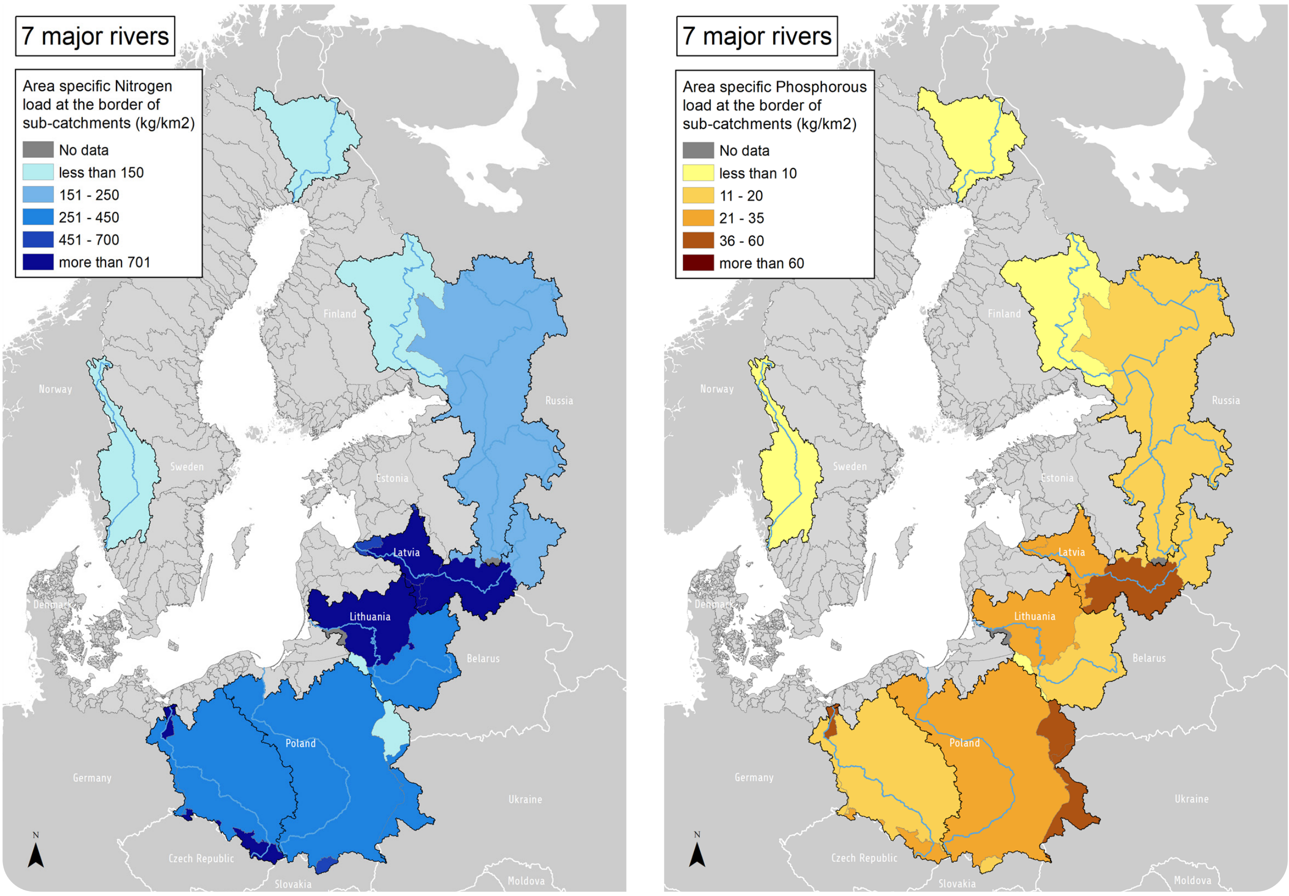


Figure 3. Area specific loads kg km-2 (load/area) of total nitrogen and total phosphorus from the catchments or sub-catchment of the seven biggest rivers in 2017.

Table 2. Area specific loads (load/area); concentrations of total nitrogen and total phosphorus in 2017 and average 2010–2017. Concentrations were calculated from annual load and flow values.

River	Area-specific TN load in kg/ km^2	Area-specific TP load in kg/ km^2	TN 2017 concentration in mg/l	TN 2010-17 ave. concen-tration in mg/l	TP 20147 concentration in mg/l	TP 2010-17 ave. concen-tration in mg/l	Runoff in 2017 (ls/ km^2
Kemijoki	133	6	0.374	0.372	0.017	0.018	1.13
Nemunas	713	22	2.787	2.408	0.087	0.079	0.95
Daugava	533	22	1.632	1.777	0.067	0.066	1.00
Oder	576	21	4.176	3.469	0.155	0.168	0.43
Vistula	567	19	3.03	2.453	0.101	0.163	0.63
Neva	192	8	0.726	0.617	0.031	0.026	0.82
Göta älv	145	4	0.576	0.626	0.017	0.017	0.80

Total annual nutrient loads from rivers depend greatly on annual average precipitation in the river basin and consequently river flow. Therefore, flow normalized values for total nitrogen and phosphorus loads are used for inter-annual comparison of loads and for analysing long term trends. In 2017 the non-normalized total nitrogen load by the big seven rivers was 372,000 t and total phosphorus load 13,500 t. The proportion of flow from the seven biggest rivers to the Baltic Sea was 30% and the respective proportions of total nitrogen and phosphorus loads were 39%. The River Neva contributed with 34% of the total flow of the seven big rivers, but the River Vistula had the highest total nitrogen and total phosphorus loads (Fig. 4).

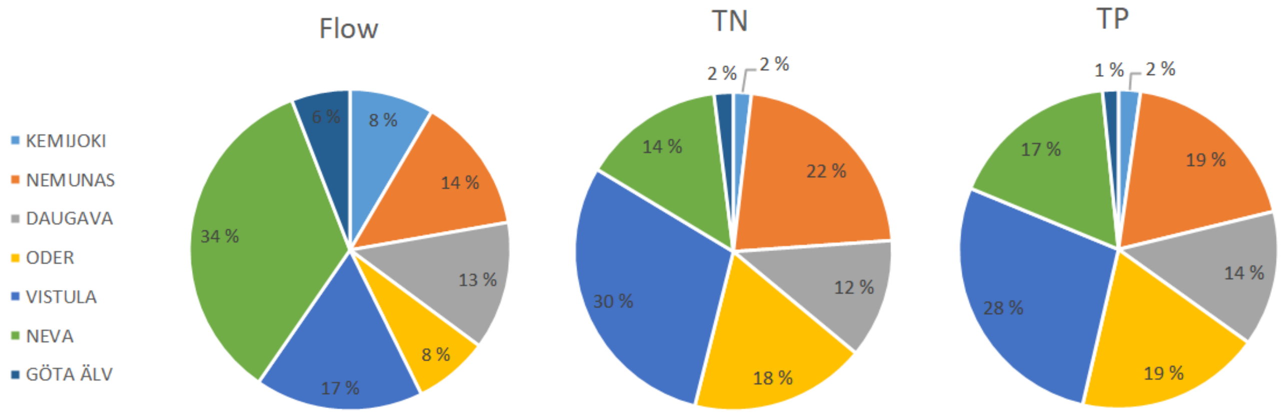


Figure 4. Proportions of the total flow, normalized total nitrogen load and normalized total phosphorus load for the seven biggest rivers of the Baltic Sea catchment area in 2017.

The total nitrogen load of the 7 biggest rivers decreased between 1995 and 2000 and thereafter the load has fluctuated according to changes in flow without a trend (Fig. 5). The total phosphorus load showed a statistically significant decrease between 1995 and 2017 (Fig. 6) and the phosphorus load was reduced by 6,000 t (30%).

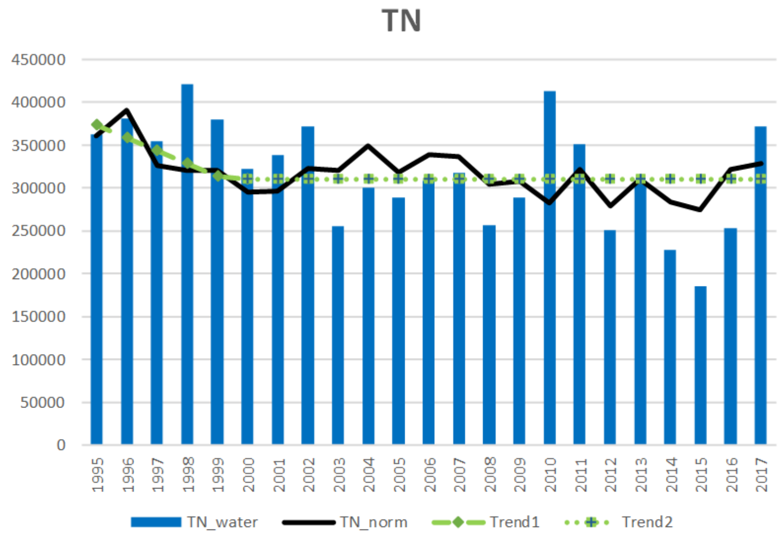


Figure 5. Total nitrogen (blue bars) load of the 7 biggest rivers between 1995 and 2017. The black line shows flow-normalized nutrient load and the green lines show linear trends with a break point in 2000. Dashed line shows statistically non-significant trend and solid line significant trend.

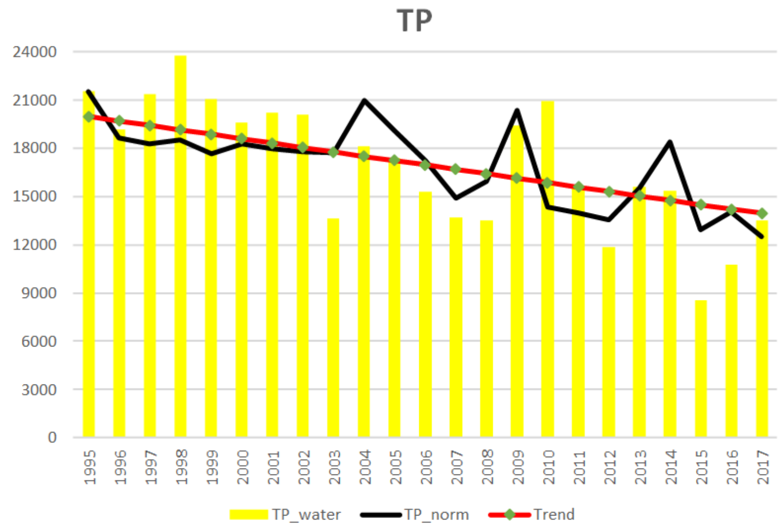


Figure 6. Total phosphorus (yellow bars) load of the 7 biggest rivers between 1995 and 2017. The black lines shows flow-normalized nutrient load and the red line shows linear trend (dashed line statistically non-significant trend, solid line significant).

3. Five biggest rivers:

National input ceilings (NIC's) and remaining reductions

The five biggest rivers around the Baltic Sea have catchment areas in several different countries and thus also large shares of nutrient loads originate in many different countries. To divide the nutrient load reductions according to their origin there are nutrient input ceilings also for these five biggest rivers (Table 3). The input ceilings for transboundary rivers are not additional requirement but an integral part of the national net input ceiling and, thus, countries are free to implement measures where they are most appropriate to meet their net input ceilings.

Table 3. TN and TP Input ceilings, estimated inputs in 2017 and remaining nutrient reductions in 2017 to fill NIC's.

TN	**Daugava**	**Nemunas**	**Neva**	**Oder**	**Vistula**	**5 biggest rivers**
A: Input ceiling (NIC)	38 800	29 338	43 476	49 298	74 807	235 719
B: Estimated input 2017*)	33 771	53 012	46 190	64 947	82 701	280 620
C: Inputs 2017 including uncertainty (test value)	37 426	57 602	51 854	67 684	90 768	305 334
Remaining reduction to fulfill NIC by 2017		28 264	8 378	18 386	15 961	**70 989**
Remaining in % of ceiling	*0*	*96*	*19*	*37*	*21*	*30*

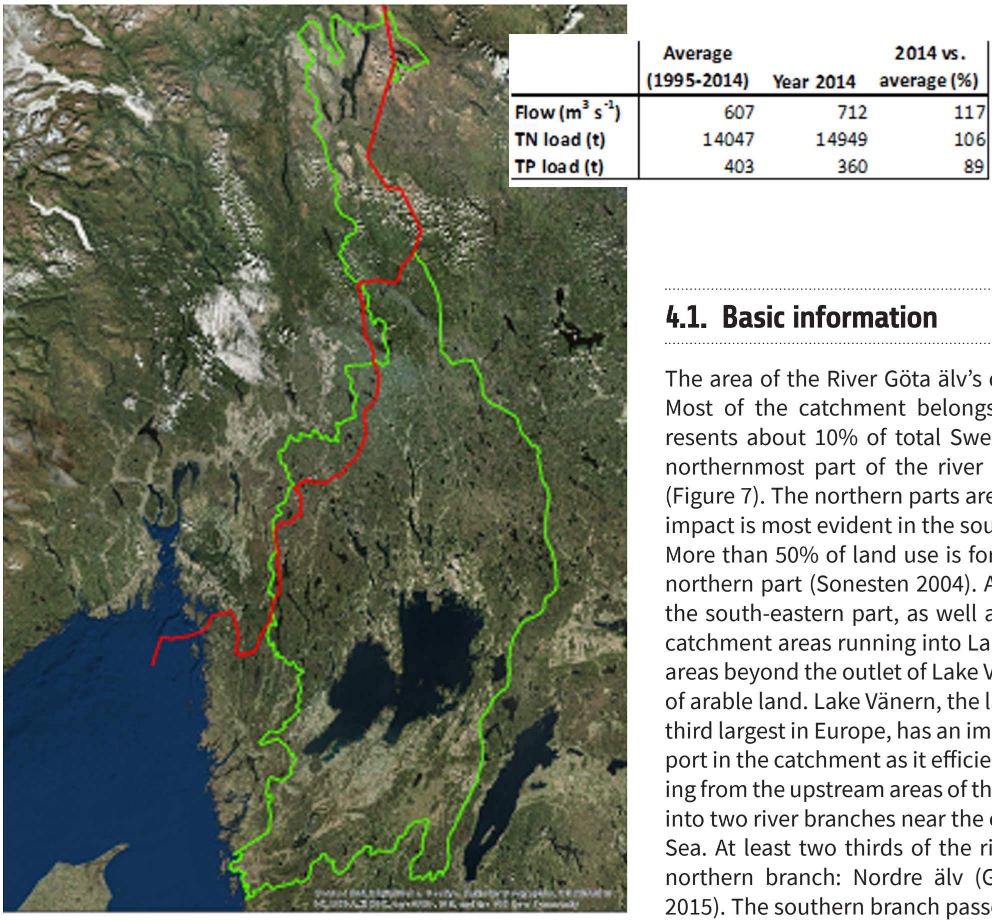
TP	**Daugava**	**Nemunas**	**Neva**	**Oder**	**Vistula**	**5 biggest rivers**
A: Input ceiling (NIC)	911	911	1 398	1 551	2 350	7 157
B: Estimated input 2017*)	1 374	1 565	2 101	2 887	6 103	14 029
C: Inputs 2017 including uncertainty (test value)	1 455	1 769	2 918	3 129	6 516	15 787
Remaining reduction to fulfill NIC by 2017	514	855	1 520	1 575	4 166	**8 630**
Remaining in % of ceiling	*55*	*94*	*109*	*101*	*177*	*121*

*)Estimation based on the trend analysis

Estimated (estimation based on trend analyses) TN inputs in 2017 of the five biggest rivers with added uncertainty were 305,000 t, which was 71,000 t more than the input ceiling of those rivers (Table 3). The proportion of the remaining TN reduction of the five biggest rivers is 56% of the total remaining TN reduction of the whole Baltic Sea. The River Daugava was the only river where the TN inputs were below the input ceiling, whereas the River Nemunas had the largest remaining reduction (28,000 t) to fulfill the NIC.

Estimated (estimation based on trend analyses) TP inputs in 2017 of the five biggest rivers with added uncertainty were 15,800 t, which was 8600 t more than the input ceiling of those rivers (Table 3). The proportion of the remaining TP reduction of the five biggest rivers is 88% of the total remaining TP reduction of the whole Baltic Sea. All rivers had remaining TP reductions in 2017 to fulfill the NIC, but nearly half of this remaining reduction was in the River Vistula.

4. The Göta älv River



	Average (1995-2014)	Year 2014	2014 vs. average (%)
Flow ($m^3 s^{-1}$)	607	712	117
TN load (t)	14047	14949	106
TP load (t)	403	360	89

Figure 7. The drainage area (green line) of the River Göta älv, country borders (red line), average flow, total nitrogen load, total phosphorus load and respective values for the year 2017.

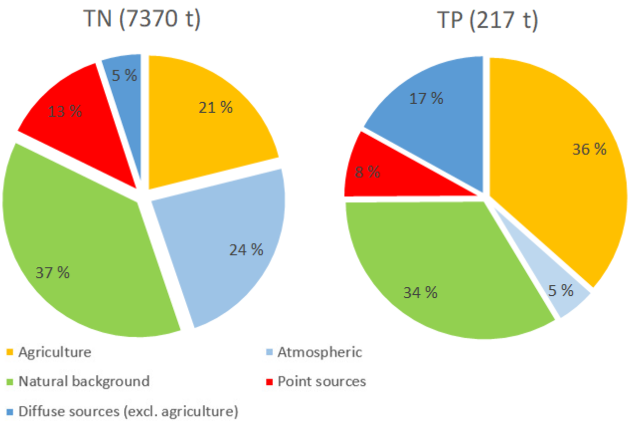


Figure 8. Nitrogen and phosphorus loads exported by the River Göta älv in 2017 divided into load sources.

4.1. Basic information

The area of the River Göta älv's drainage basin is 50,200 km2. Most of the catchment belongs to Sweden (85%) and represents about 10% of total Swedish land area. However, the northernmost part of the river system is located in Norway (Figure 7). The northern parts are pristine, whereas the human impact is most evident in the southern parts of the catchment. More than 50% of land use is forested areas, especially in the northern part (Sonesten 2004). Arable land is mainly found in the south-eastern part, as well as in the lower reaches of the catchment areas running into Lake Vänern (Figure 6). Also, the areas beyond the outlet of Lake Vänern have a notable amount of arable land. Lake Vänern, the largest lake in Sweden and the third largest in Europe, has an import role in the nutrient transport in the catchment as it efficiently retains nutrients originating from the upstream areas of the catchment. The river divides into two river branches near the estuary leading into the North Sea. At least two thirds of the river volume runs through the northern branch: Nordre älv (Göta älvs vattenvårdsförbund 2015). The southern branch passes through the city of Gothenburg providing more than 700 000 people with drinking water. The River Göta älv is utilized as a shipping channel and allows for transport of goods both in the upstream and downstream direction. The total fall in height between lake Vänern and the sea is 44 meters. This is used for producing hydropower through a highly regulated water flow in several water power plants, corresponding to a total capacity of approximately 300 MW. The River Göta älv is a recipient for wastewater from various industries, sewage treatment plants and individual sewers as well as storm water from urban areas and nutrient input from agriculture in the catchment area. Population density is 28 inhabitants per km2 and Karlstad, Trollhättan and Gothenburg are the largest cities in the catchment.

Natural background leaching was the main source of nitrogen (37%) of the River Göta älv in 2017, whereas agriculture comprised the largest proportion (36%) of the phosphorus load followed by natural leaching (Fig. 8). Beside agriculture atmospheric deposition was an important contributor to the nitrogen loads. Point sources contributed with 13% of TN load and 8% of the TP load respectively.

4.2. Trends in the export: The River Göta älv

In 2017 flow was less than 70% of the long-term average flow, which was reflected in the low N export (7,300 t) and P export (217 t). N export was only half of the long-term average export and P export 62%, respectively. In 2017 the area specific total nitrogen load was 145 kg km-2 and the mean total nitrogen concentration was 576 µg l-1. The respective total phosphorus load was 4.3 kg km-2 and the mean concentration was 17 µg l-1. Total nitrogen loads dropped in 2002 and have been decreasing after that (Fig. 9). In fact, the total nitrogen load has been decreasing since the mid 1980's. This is a general tendency for nitrogen transport in different parts of the river system as well as for the nitrogen levels in Lake Vänern. The reduced nitrogen levels in the system are due to reduced inputs of nitrogen from point sources (Christensen et al. 2002) including nitrogen removal from wastewater treatment plants, and also from diffuse nitrogen sources. Total phosphorus loads do not show any statistically significant changes (Fig. 9). There was a better correlation between flow and total nitrogen load than between flow and total phosphorus load (Figure 10), indicating that nitrogen is more easily leached from soils into freshwaters during rain events.

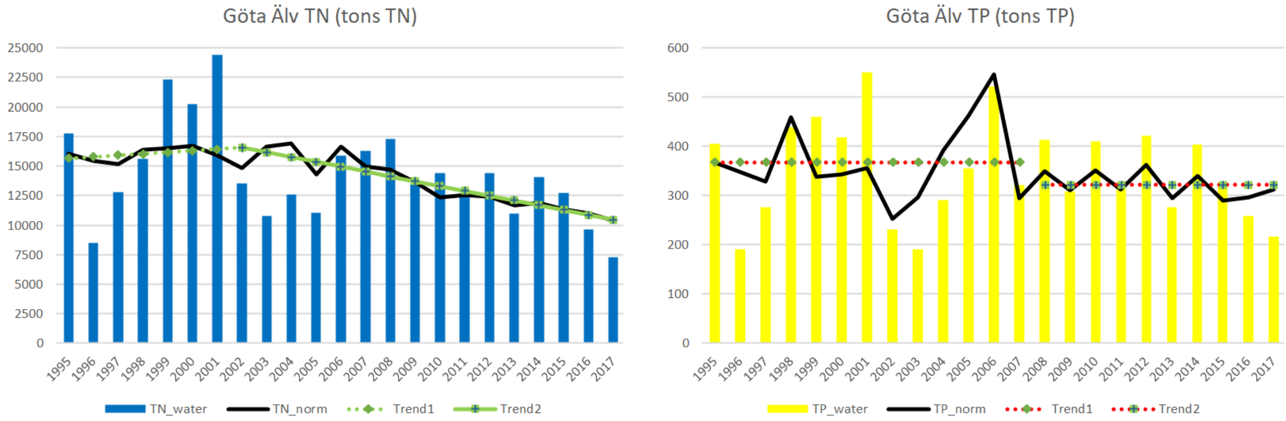


Figure 9. Total N (blue bars) and total P export (yellow bars) by the River Göta älv from 1995 to 2017. The black lines are showing flow-normalised nutrient export and the green lines the trend in the flow-normalised export. Solid green lines indicate statistically significant trend and dashed lines non-significant trend.

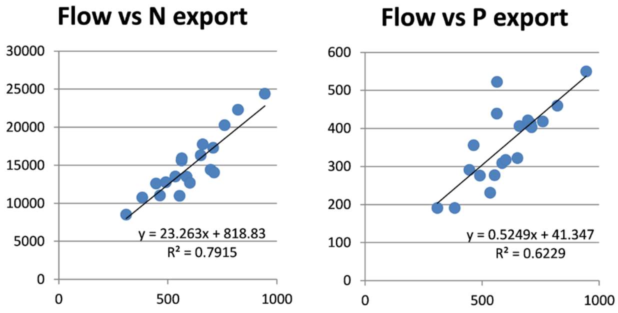
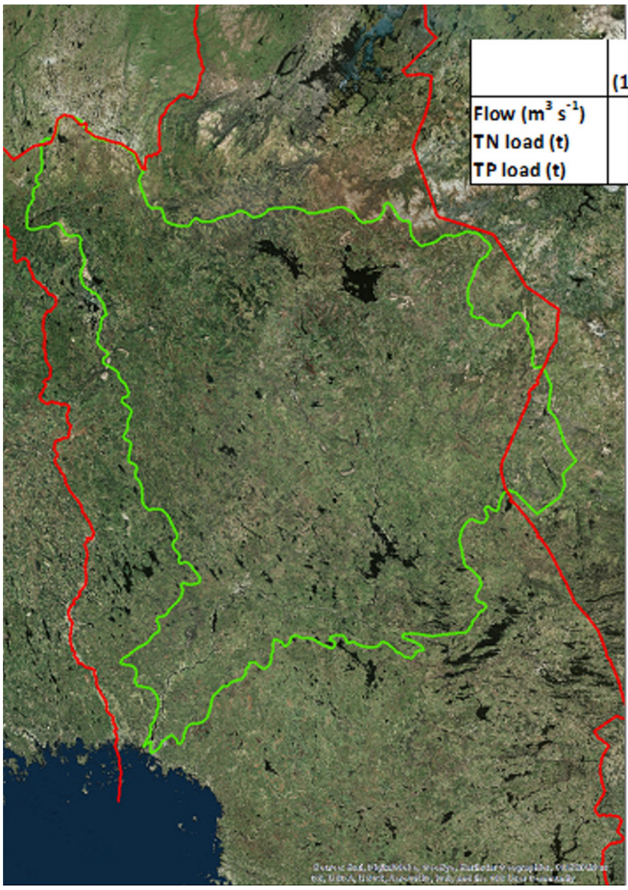


Figure 10. The relationship between water flow and NTOT & PTOT export.

5. The Kemi River



	Average (1995-2014)	Year 2014	2014 vs. average (%)
Flow ($m^3 s^{-1}$)	559	495	89
TN load (t)	6492	5671	87
TP load (t)	328	262	80

Figure 11. The drainage area (green line) of the Kemi River, country borders (red line), average flow, total nitrogen load, total phosphorus load and respective values for the year 2017.

5.1. Basic information

The River Kemi stretches for 550 km, making it the longest river in Finland. It flows into the Bothnian Bay. It drains the northern parts of Finland and a small part of its catchment is in Russian territory (Fig. 11). The river has been intensively used for hydroelectric production and the first dam was built in 1946. Today the total number of hydroelectric plants is twenty-one. In addition to dams, two large reservoirs were built in the late 1960s in the northern parts of the catchment for hydroelectric purposes. Forests cover over half and peatlands one quarter of the catchment area. The northernmost parts of the catchment area are in particularly pristine condition. Human impact, beside hydroelectric production, is mainly due to forestry activities. In addition, there are about 20 peat production areas and three mines. The only other industrial activity contributing to the pollution load was the pulp factory in Kemijärvi, but this closed in 2008. Most of the cultivated areas and the majority of settlements are located in the lower parts of the catchment. Agricultural land areas and urban areas cover together less than 1% of the total catchment area and the population density is only 2 people per km2. The largest city in the area is Rovaniemi with 62,000 inhabitants.

The major share (75%) of nutrients exported to the Baltic Sea from the River Kemi in 2017 originated from natural leaching (Fig.12). Agriculture's share of the total nitrogen load was 7% and 11% of the phosphorus load. In addition to agriculture, forestry was an important phosphorus load source in the River Kemijoki catchment.

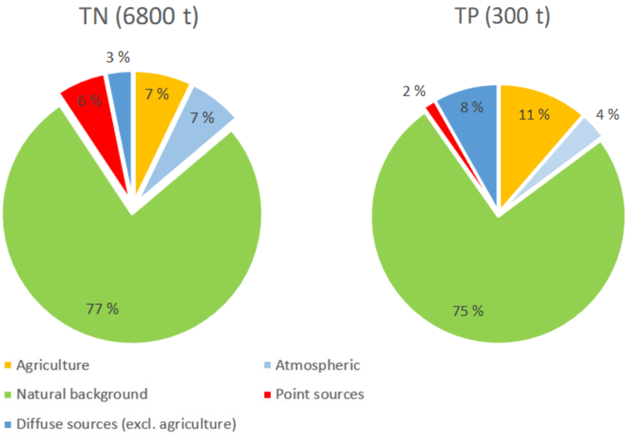


Figure 12. The relationship between water flow and NTOT & PTOT export.

5.2. Trends in the export: The Kemi River

In 2017 flow was at the same level as the long-term average flow and this was reflected in total nitrogen loads, which was the same as the long-term TN load, whereas TP load was slightly lower. In 2017 the area specific total nitrogen load was 133 kg km-2 and the mean total nitrogen concentration was 374 µg l-1. The respective total phosphorus load was 5.9 kg km-2 and the concentration was 17 µg l-1. No statistically significant trends could be detected between 1995 and 2017 (Figure 13). However, climate change is projected to increase precipitation and runoff especially in the northern parts of the Baltic Sea over the next century (Graham 2004) and there are signs that flow is increasing in northernmost Finland (Räike et al. 2014), which will most likely lead to an increase in nutrient transport to the sea. Approximately half of the annual nutrients in the River Kemi are exported to the sea during spring floods in May to early June. However, the timing of floods is changing and the spring thaw is expected to start earlier in future (Blöschl et al. 2017). There was a good correlation between flow and loads for both total nitrogen and total phosphorus (Figure 14).

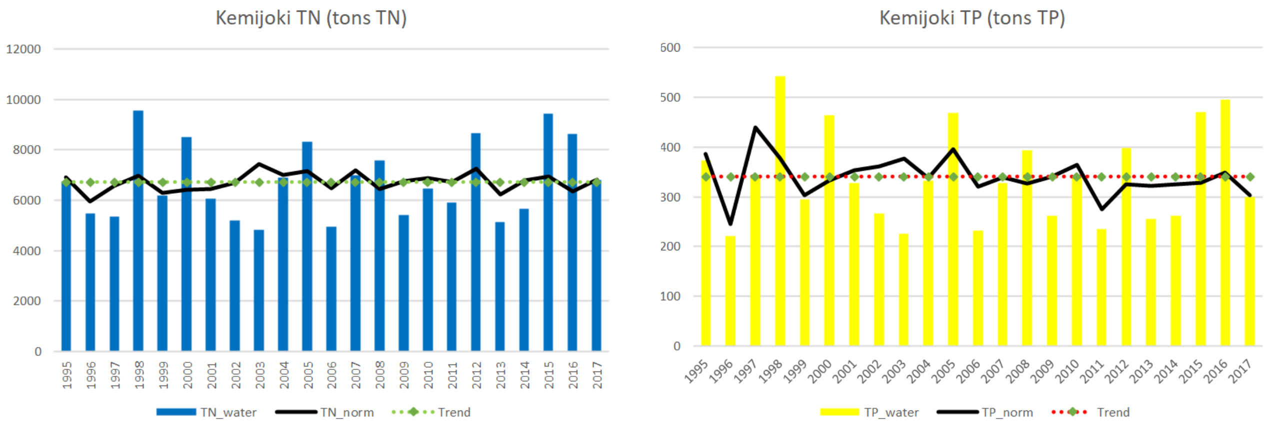


Figure 13. Total N (blue bars) and total P export (yellow bars) by the Kemi River from 1995 to 2017. The black lines are showing flow-normalised nutrient export and the green lines the trend in the flow-normalised export. Solid lines indicate statistically significant trend and dashed lines non-significant trend.

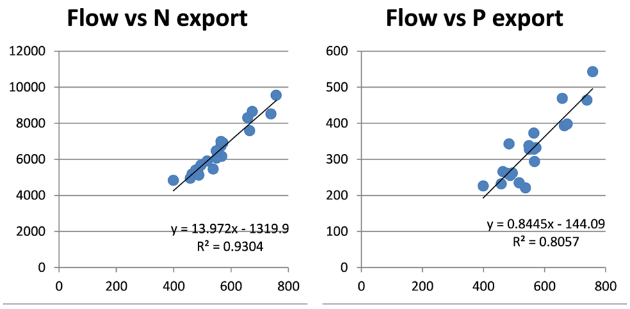
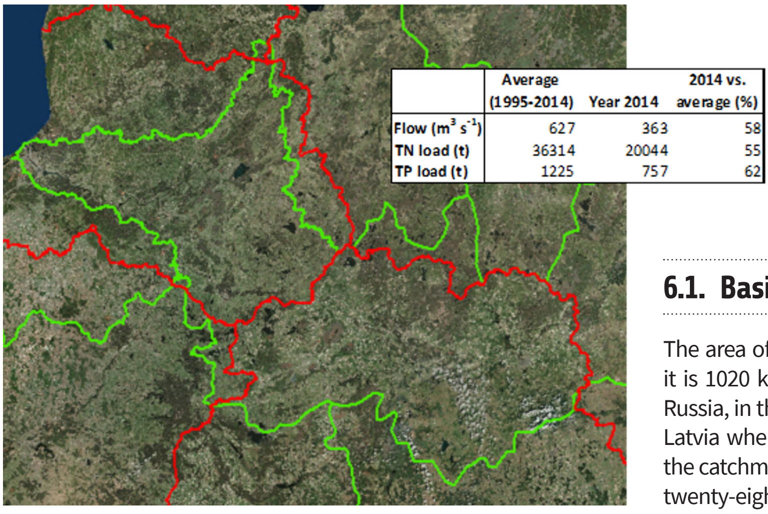


Figure 14. Nitrogen and phosphorus loads exported by the Kemi River divided into load sources.

6. The Daugava River



	Average (1995-2014)	Year 2014	2014 vs. average (%)
Flow ($m^3 s^{-1}$)	627	363	58
TN load (t)	36314	20044	55
TP load (t)	1225	757	62

Figure 15. The drainage area (green line) of the Daugava River, country borders (red line), average flow, total nitrogen load, total phosphorus load and respective values for the year 2017.

6.1. Basic information

The area of the Daugava River's drainage basin is 87,900 km2 and it is 1020 km long (Fig. 15). The Daugava River begins in western Russia, in the Valdai Hills, and crosses the territories of Belarus and Latvia where it flows into the Gulf of Riga. Thirty-eight percent of the catchment belongs to Belarus, thirty-one percent to Russia and twenty-eight percent to Latvia. The rest of the Daugava catchment belongs to Lithuania and Estonia.

Forests cover around half of the Daugava catchment, and cultivated areas occupy around 20%. Population density varies greatly, being the highest in the area around Riga. Several large towns in Latvia and Belarus are located on the banks of Daugava River: Riga (700 000 inhabitants), Ogre (27 000 inhabitants), Daugavpils (94 000 inhabitants), Navapolatsk (108 000 inhabitants), Polatsk (82 000 inhabitants) and Vitebsk (366 000 inhabitants). Deterioration of water quality of the Daugava River started during the Soviet era, when large factories and new residential areas were built without the necessary sewage treatment plants. Navapolatsk town is one of the major sources of pollution to the Daugava River due to its oil processing, refinery plants and developed chemical industry. Municipal waste water treatment plants and agricultural activities are also considerable sources of pollution.

The ecosystem of the lower reaches of the Daugava is strongly influenced by the dams and reservoirs of three hydroelectric power plants: Plavinas, Kegums and Rīga. Belarus also has a goal to construct a cascade of four hydroelectricity plants on the Daugava River (Polotsk, Vitebsk, Beshenkovichi, and Verkhnedvinsk), with a total capacity of up to 130 MW by 2020. Presently Vitebsk and Polotsk hydropower plants are under construction and currently they operate on a test regime.

The largest proportion of the Daugava's nutrient inputs are transboundary, originating from countries upstream from Latvia (Fig. 16). The Latvian part in 2017 (49% of TN and 29% of TP) came mainly from diffuse sources, but there is no data available of more detailed division (e.g. agriculture, scattered dwellings). Natural background inputs and point source loads were of minor importance in Latvian inputs into the Daugava River.

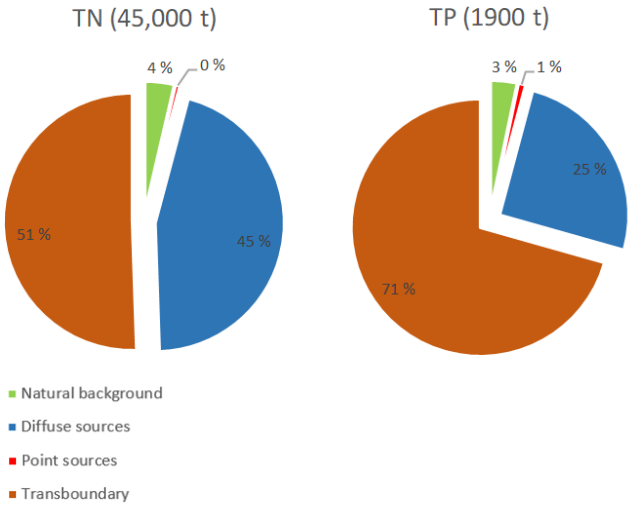


Figure 16. Nitrogen and phosphorus loads exported by the Daugava River in 2017 divided into load sources.

6.2. Trends in the export: The Daugava River

In 2017 flow was nearly 40% higher than the long term mean flow and nutrient loads were also 25–35% above the long term mean: 43,000 t total nitrogen and 180 t total phosphorus. In 2017 the area specific total nitrogen load was 513 kg km-2 and the mean total nitrogen concentration was 1630 µg l-1. The respective total phosphorus load was 21 kg km-2 and the total phosphorus concentration was 67 µg l-1.

Major reduction in anthropogenic loading in Latvia occurred between 1987 and 1996 when consumption of fertilizers and number of livestock drastically decreased (Stålnacke et al. 2003). There were no statistically significant trends in total nitrogen or phosphorous loads between 1995 and 2017 (Fig. 17). Changes in analytical methods have hampered the estimation of changes in load, as nutrient load calculation up until 2003-2004 were based on filtered samples, thus underestimating the total loads. This is supported by abrupt changes in DIP/TP (dissolved inorganic phosphorus/total phosphorus) ratio, which occurred at that time (Savchuck et al. 2012).

The correlation between flow and load for Daugava (Fig. 18) is weaker than the respective correlation of the Göta älv and Kemi rivers. Processes such as input of waste water, nutrient uptake by vegetation or retention in reservoirs can weaken the relationships between flow and nutrient loads. Highest nutrient concentrations in Latvian rivers are observed in spring when nutrients are flushed out from the catchment soils (Klavins et al. 2003). Around 40 % of the annual flow occurs in spring (Apsite et al. 2009), but future projections predict substantial reduction of spring flow and increase of winter flow (Latkovska et al. 2012).

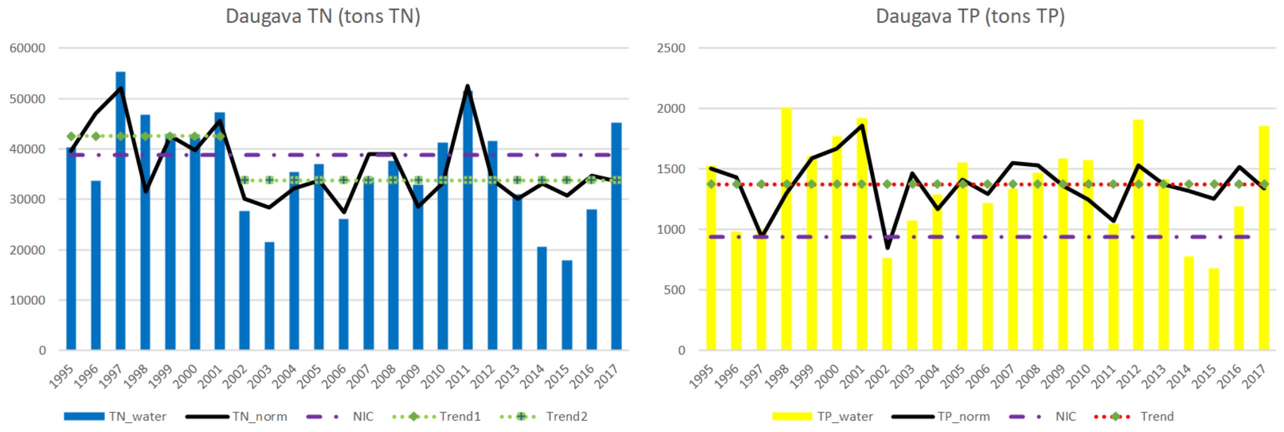


Figure 17. Total N (blue bars) and total P export (yellow bars) by the Daugava River from 1995 to 2017. The black lines are showing flow-normalised nutrient export and the green lines the trend in the flow-normalised export. Solid lines indicate statistically significant trend and dashed lines non-significant trend.

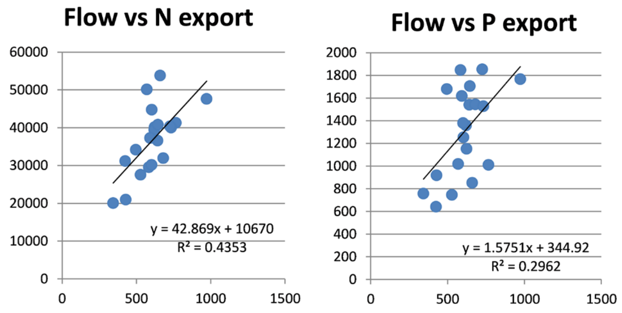
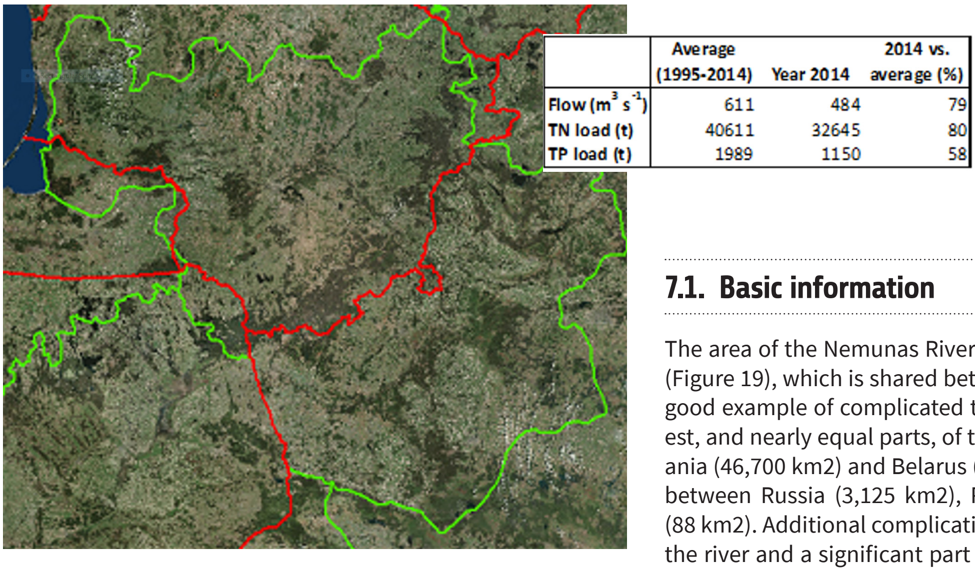


Figure 18. The relationship between water flow and NTOT & PTOT export.

7. The Nemunas River



	Average (1995-2014)	Year 2014	2014 vs. average (%)
Flow ($m^3 s^{-1}$)	611	484	79
TN load (t)	40611	32645	80
TP load (t)	1989	1150	58

Figure 19. The drainage area (green line) of the Nemunas River, country borders (red line), average flow, total nitrogen load, total phosphorus load and respective values for the year 2017.

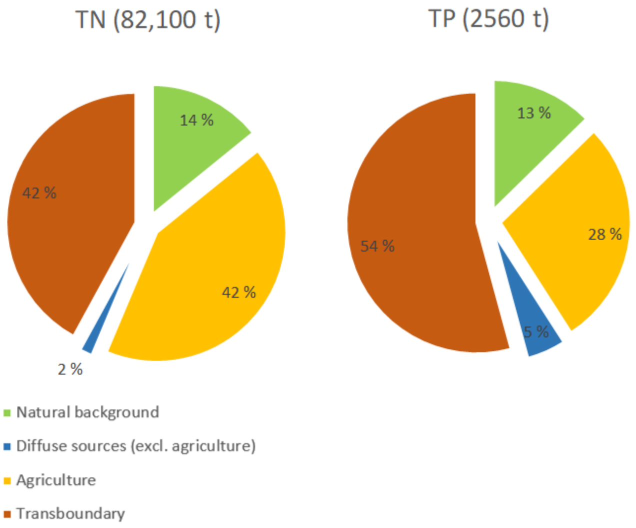


Figure 20. Nitrogen and phosphorus loads exported by the Nemunas River in 2017 divided into load sources.

7.1. Basic information

The area of the Nemunas River's drainage basin is 97,900 km2 (Figure 19), which is shared between five countries making it a good example of complicated transboundary issues. The largest, and nearly equal parts, of the catchment belongs to Lithuania (46,700 km2) and Belarus (45,463 km2). The rest is shared between Russia (3,125 km2), Poland (2,515 km2) and Latvia (88 km2). Additional complication arises because the mouth of the river and a significant part of downstream water is shared between two countries: Lithuania and Russia, making it at the same time a transboundary and border river, which is a unique combination in the Baltic Sea drainage basin. Moreover, it all gets even more complex because of the Matrosovka channel, which at 50 km from the river mouth diverts one quarter of all Nemunas river volume into Russian territory.

The total length of the Nemunas River is 937 km. It is the fourth longest river in the Baltic Sea basin. 436 km of it flows in Belarus, 359 km in Lithuania and the remaining 116 km stretch is the border between Lithuania and Russia's Kaliningrad oblast. Land cover in the Nemunas River basin is dominated by agricultural land, which occupy more than half of the basin area in Lithuania. Forest and natural areas make up around one-third, while surface water bodies and urban areas cover 2% of the basin each (Table 1). Total population in the basin is estimated at around 5.4 million people and the biggest city is Vilnius with around 543,000 inhabitants. There is only one major reservoir in the Nemunas River, which was built for hydroelectric power generation in 1960, close to Kaunas (Lithuania). Another hydroelectric power generation station was built close to Grodno city (Belarus) in 2012. However, it was built using run-of-the-river hydroelectricity, meaning that no reservoir was needed.

Over 40% of the TN load and 54% of the TP load was transboundary in 2017 i.e. transported into Lithuania from the upstream countries (Fig. 20). The Lithuanian inputs came mainly from agriculture (58% of TN and 46% of TP). There was no point source data available for the source apportionment.

7.2. Trends in the export: The Nemunas River

In 2017 flow was 51% higher than the long-term average flow. Respectively also nutrient export increased: The N export nearly doubled compared to the long-term average being 82,000 t and P export (2560 t) was 31% above the average level. In 2017 the area specific total nitrogen load was 838 kg km-2 and the mean total nitrogen concentration was 2790 µg l-1. The respective total phosphorus load was 26 kg km-2 and total phosphorus concentration 87 µg l-1.

Two trends can be observed in the time series of total nitrogen load: up to until 2003 total nitrogen loads were decreasing, while after 2003 the opposite trend emerged (Fig. 21), which happened due to an increase in the intensity of agricultural activities. In 2017 TN load was 39% higher compared to the respective load in the reference period (1997–2003). From 2001 onwards the area under cultivation and fertilizer usage gradually increased. A distinct drop in total phosphorus load happened during 2004-2005, around the time when Lithuania joined the European Union. This was due to large investments in the upgrading and building of new waste water treatment facilities, largely financed by the European Union. In 2017 TP load was 35% lower compared to the respective load in the reference period (1997–2003).

The correlation between flow and total phosphorus load was very weak (Fig. 22), while the correlation between flow and total nitrogen load is more pronounced.

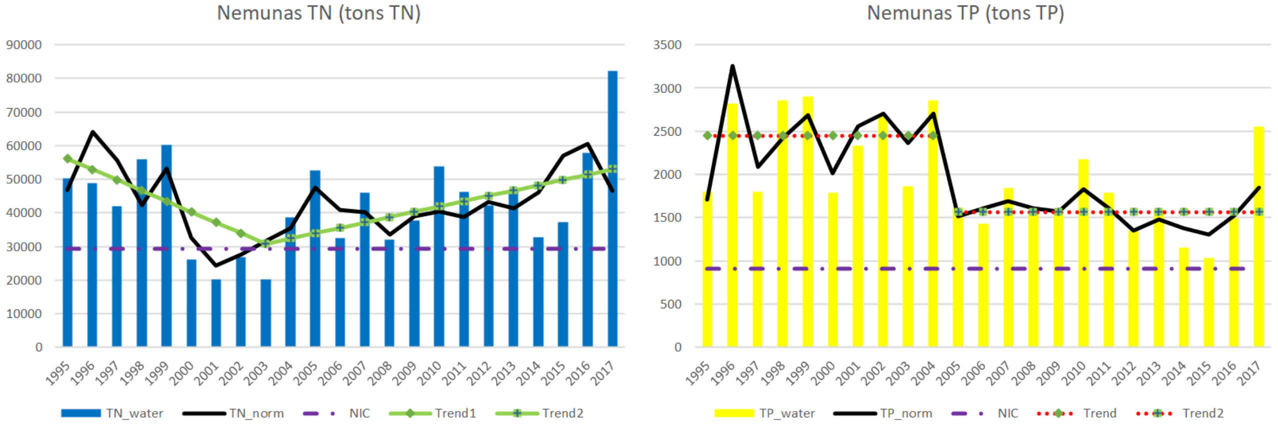


Figure 21. Total N (blue bars) and total P export (yellow bars) by the Nemunas River from 1995 to 2017. The black lines are showing flow-normalised nutrient export and the green lines the trend in the flow-normalised export. Solid lines indicate statistically significant trend and dashed lines non-significant trend.

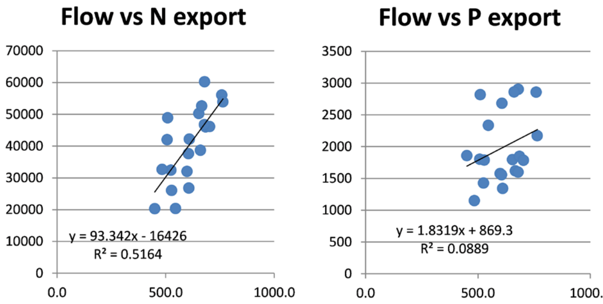
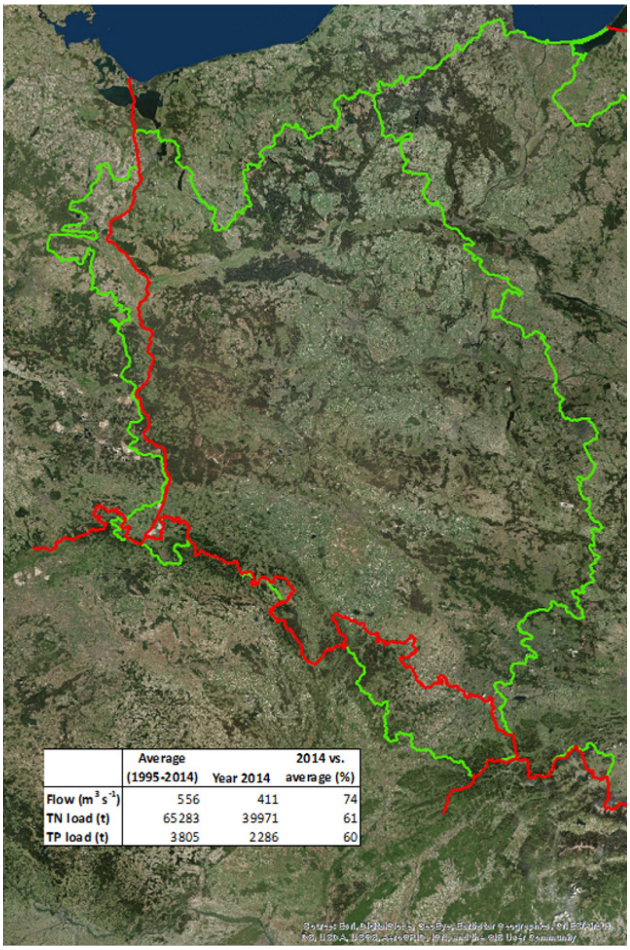


Figure 22. The relationship between water flow and NTOT & PTOT export.

8. The Oder River



	Average (1995-2014)	Year 2014	2014 vs. average (%)
Flow ($m^3 s^{-1}$)	556	411	74
TN load (t)	65283	39971	61
TP load (t)	3805	2286	60

Figure 23. The drainage area (green line) of the Oder River, country borders (red line) and average flow, total nitrogen load, total phosphorus load and the respective values for the year 2017.

8.1. Basic information

The source of the Oder River is in the Czech Republic in the Odrzanskie Mountains at an altitude of 634 m above sea level (Figure 23). The river is 841 km long and the area of river basin is 124,049 km2, of which 107,000 km2 is in Poland (86%), 7,300 km2 in the Czech Republic (6%), and 9,600 km2 within the boundaries of Germany (8%). The Oder flows into the Szczecin Lagoon. Beside pollution from municipal waste water treatment plants and scattered dwellings a large share of nutrient load originates from cultivated areas, which cover nearly 50% of the Oder's catchment area (Table1). Over 16 million people live in the Oder River catchment and the population density is high. Large cities include Ostrava, Opole, Frankfurt, Poznan, Wroclaw, and Szczecin.

In the Oder River in 2017–2018 61% of the TN load originated from agriculture and 42% of the TP load respectively (Fig. 24). Point sources were a remarkable TP load source with a proportion of 27%. Transboundary inputs comprised 14-21% of the nutrient loads.

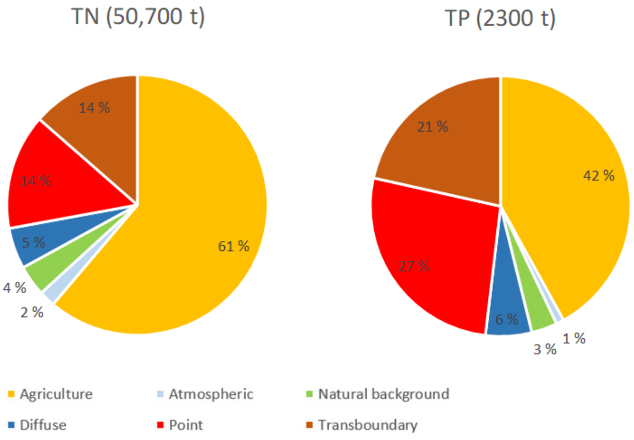


Figure 24. Nitrogen and phosphorus loads exported by the Oder River in in 2017 (Germany) and 2018 (Poland) divided into load sources.

8.2. Trends in the export: The Oder River

In 2017 flow slightly lower than the long-term average flow. The N export was 66,000 t and P export 2500 t. The area specific total nitrogen load was in 564 kg km-2 and the mean total nitrogen concentration was 4130 µg l-1. The respective total phosphorus load was 21 kg km-2 and total phosphorus concentration was 156 µg l-1.

There was a significant decrease in P export from 1995 to 2017, but no trend in N export (Fig 25). In 2017 TP load was 29% lower compared to the respective load in the reference period (1997–2003). To some extent, the changes in nutrient inputs from the Oder to the Baltic may be explained by developments in wastewater management and in agriculture. In Poland the 1990's were a period of stagnation in agriculture and of major investments in wastewater treatment plants, prompted by the adoption in 1991 of regulations requiring nitrogen and phosphorus removal in all wastewater treatment plants. From the early 2000's onwards, and particularly since Poland's accession to the European Union, there has been a pronounced increase in the intensity of agriculture, including a growth in the use of mineral fertilizers, to some degree offset by the implementation of more environment-friendly agricultural practices concerning natural and mineral fertilizer use. The net effect of the changes in wastewater treatment and agriculture was a slow reduction in nutrient inputs to the Baltic. There is little doubt that in the past decade nutrient loads (particularly nitrogen) from large wastewater treatment plants continued to decline. However, the apparent recent surge in phosphorus inputs, if confirmed by future monitoring, could be associated with the fact that in 2006 regulations concerning effluent quality were relaxed, allowing smaller wastewater treatment plants not to remove phosphorus upon expiry of their pre-2006 permits. This rather complex picture is further altered by the irregularity of flows, including the 2010 flood which resulted in a strong spike in actual nitrogen and phosphorus inputs.

Correlation between flow and total nitrogen load is more pronounced than the correlation between flow and total phosphorus load (Fig. 26).

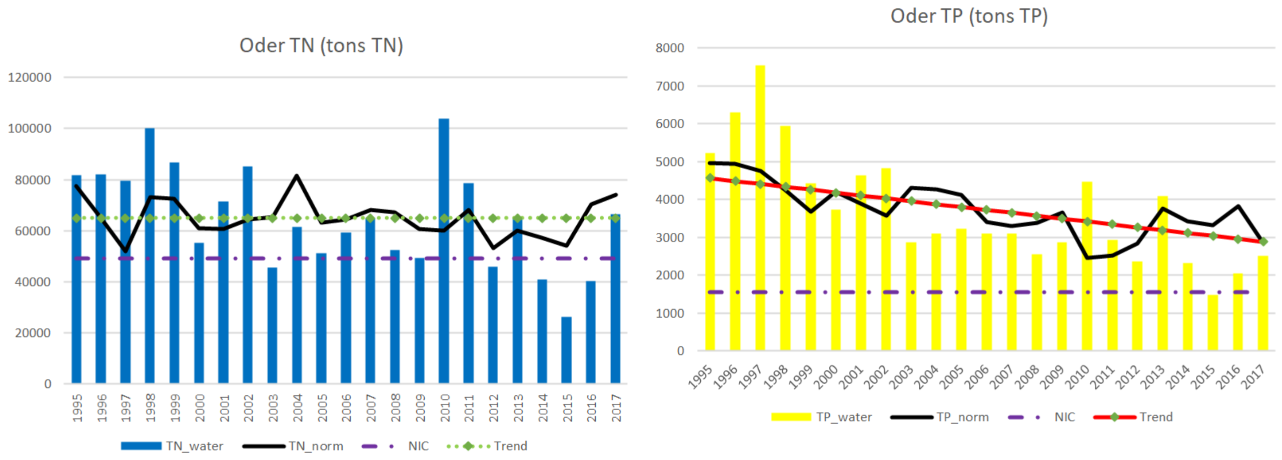


Figure 25. Total N (blue bars) and total P export (yellow bars) by the Oder River from 1995 to 2017. The black lines are showing flow-normalised nutrient export and the green lines the trend in the flow-normalised export. Solid lines indicate statistically significant trend and dashed lines non-significant trend.

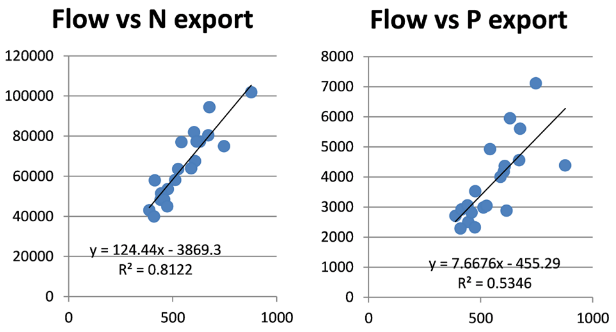
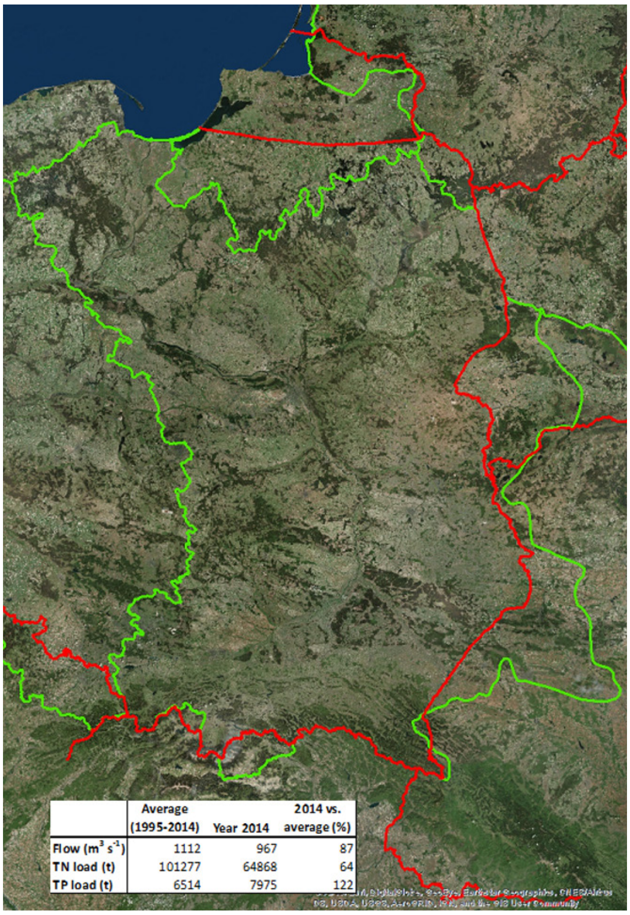


Figure 26. The relationship between water flow and NTOT & PTOT export.

9. The Vistula River



	Average (1995-2014)	Year 2014	2014 vs. average (%)
Flow ($m^3 s^{-1}$)	1112	967	87
TN load (t)	101277	64868	64
TP load (t)	6514	7975	122

Figure 27. The drainage area (green line) of the Vistula River, country borders (red line) and average flow, total nitrogen load, total phosphorus load and respective values for the year 2017.

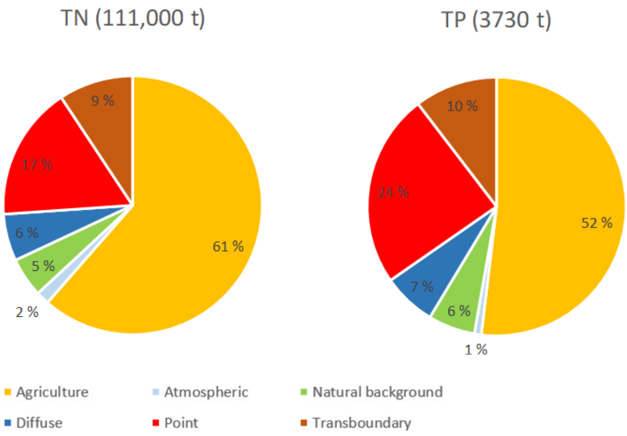


Figure 28. Nitrogen and phosphorus loads exported by the Vistula River in 2017 divided into load sources.

9.1. Basic information

The area of the Vistula River's drainage basin is 194,000 km2. The source of the Vistula River is located in the southern part of Poland and the mouth of Vistula River is in the Bay of Gdansk. The largest part of the catchment belongs to Poland (Figure 27). It is densely populated and intensively cultivated, which is reflected in high area specific loads.

The Vistula river's Polish catchment area covers about 183 176 km2 which is approximately 59% of the total surface area of Poland. 88% of the Vistula river basin is located in Poland, the remaining part is on the territories of Belarus, Ukraine and Slovakia. The river basin of the Vistula covers almost the entire eastern part of the country and it is inhabited by nearly 21 million people, which is more than half of Poland's population. The largest cities are Krakow, Warsaw and Gdansk.

The most important factors responsible for diffuse sources of pollution are agriculture, scattered dwellings and atmospheric deposition. The agricultural land covers about 50% and forests about 30% of the total Vistula river basin area (Table 1). In the Vistula catchment area the major sources of point source pollution are municipal wastewater treatment plants, but pollution also originates from industrial activities including the crude oil processing, organic and inorganic chemistry plants, paper production, textile industry, iron and steel metallurgy, food industry and shipyards. Another anthropogenic pressure originates from water discharge from mine drainage and leachate from landfills that are not properly protected.

Over half of nutrient loads of the Vistula River in 2017 originated from agriculture: 61% of the TN load and 52% of the TP load (Fig. 28). Point sources were also a remarkable nutrient load source with a proportion of 17% TN and 24% TP. Approximately 10% of nutrient loads were transboundary.

9.2. Trends in the export: The Vistula River

In 2017 flow was slightly higher than the long-term average flow. In 2017 N export was 111,000 t and P export 3730 t. The area specific total nitrogen load was 605 kg km-2 and the mean total nitrogen concentration was 3050 µg l-1. The respective total phosphorus load was 20 kg km-2 and mean total phosphorus concentration was 103 µg l-1.

There was a sharp decrease in total nitrogen load from 1995 to 1999 and after that the downward trend was more modest (Fig. 29). Total nitrogen load has decreased by 15% since the reference period (1997–2003). There was no trend in phosphorus load. To a large extent, the changes in nutrient inputs from the Vistula to the Baltic may be explained by developments in wastewater management and in agricultural practices. The 1990’s were a period of stagnation in agriculture and of major investments in wastewater treatment plants, prompted by the adoption of regulations requiring nitrogen and phosphorus removal in all wastewater treatment plants in 1991. From the early 2000’s onwards, and particularly since Poland’s accession to the European Union, there has been a pronounced increase in the intensity of agriculture, including a growth in the use of mineral fertilizers, to some degree offset by the implementation of more environmentally-friendly agricultural practices concerning natural and mineral fertilizer use. The apparent recent surge in phosphorus inputs, if confirmed by future monitoring, could be associated with the fact that in 2006 regulations concerning effluent quality were relaxed, allowing smaller wastewater treatment plants not to remove phosphorus upon expiry of their pre-2006 permits. This rather complex picture is further altered by the irregularity of flows, including the 2010 floods which resulted in a pronounced peak in actual nitrogen and phosphorus inputs.

There was a good correlation between flow and load for both nitrogen and phosphorus (Fig. 30).

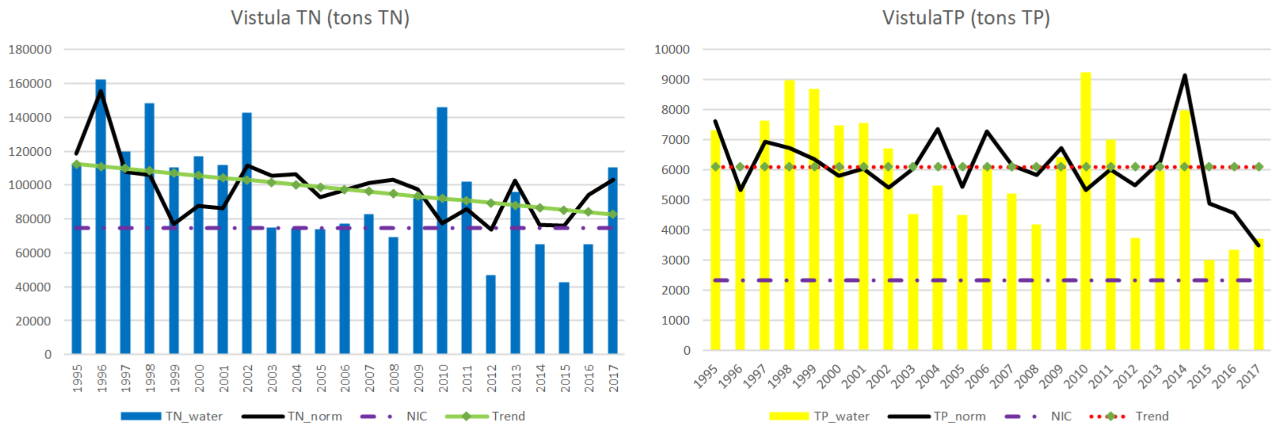


Figure 29. Total N (blue bars) and total P export (yellow bars) by the Vistula River from 1995 to 2017. The black lines are showing flow-normalised nutrient export and the green lines the trend in the flow-normalised export. Solid lines indicate statistically significant trend and dashed lines non-significant trend.

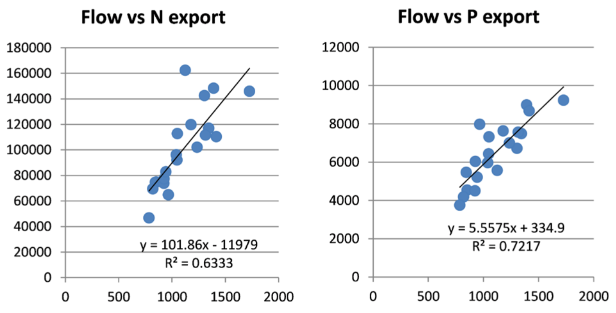
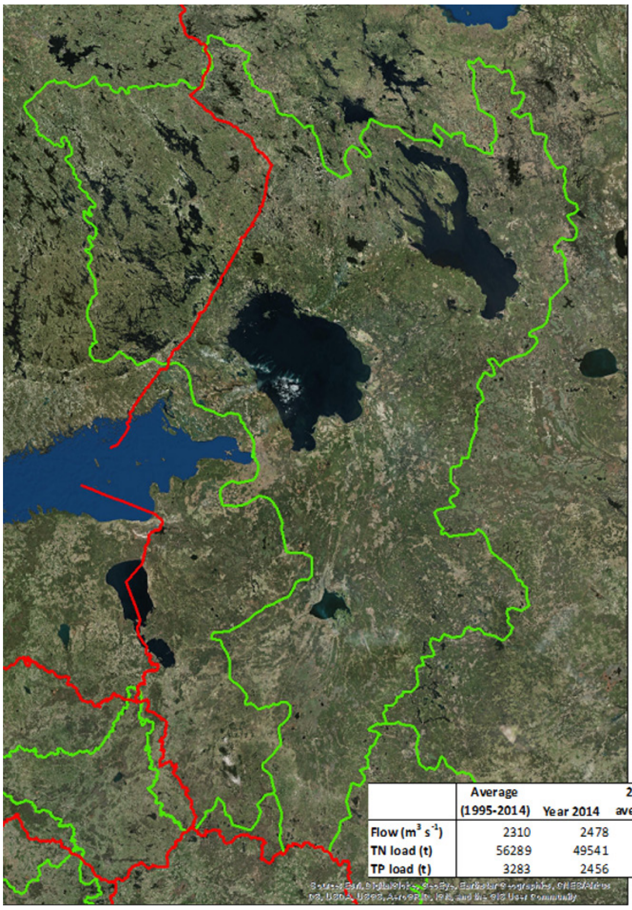


Figure 30. The relationship between water flow and NTOT & PTOT export.

10. The Neva River



	Average (1995-2014)	Year 2014	2014 vs. average (%)
Flow ($m^3 s^{-1}$)	2310	2478	107
TN load (t)	56289	49541	88
TP load (t)	3283	2456	75

Figure 31. The drainage area (green line) of the Neva River, country borders (red line) and average flow, total nitrogen load, total phosphorus load and respective values for the year 2017.

10.1. Basic information

The Neva River has the largest drainage basin of all Baltic rivers: 281 600 km2. The biggest part of the catchment belongs to Russia, but also a large area is in Finnish territory (Figure 31). The north-eastern parts are in a pristine state, whereas the areas along the riverside are densely populated. Europe's two largest lakes (Ladoga and Onega) are situated in the catchment area and they retain a large share of the nutrient inputs from their upstream catchment. Forests cover 55% of the catchment area, whereas urban and cultivated areas together cover only approximately 12% (Table 1).

Over half of the Neva's nutrient inputs in 2017 originated from natural background leaching (Fig. 32). Nearly one third of the TN load came from diffuse sources other than agriculture, whereas point sources were the second largest TP load source.

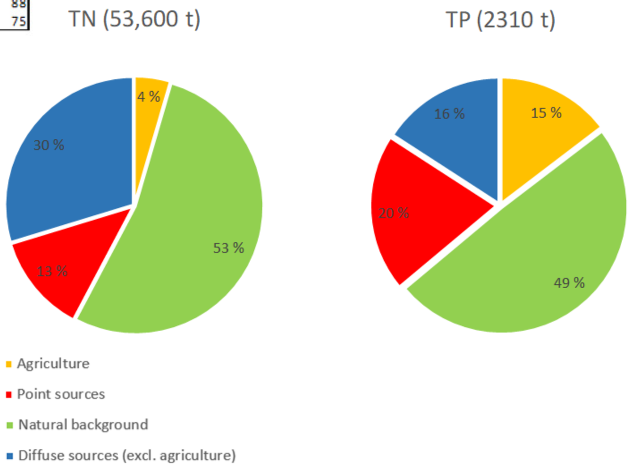


Figure 32. Nitrogen and phosphorus loads exported by the Neva River in 2017 divided into load sources.

10.2. Trends in the export: The Neva River

In 2017 flow was at the same level than the long term averages. Also both N and P export was at the average level: N export was 53,600 t and P export 2310 t. The area specific total nitrogen load was 190 kg km-2 and the mean total nitrogen concentration was 730 µg l-1. The total phosphorus load was 8 kg km-2 and the mean total phosphorus concentration was 31 µg l-1.

Nitrogen load in the Neva River increased between 1995 and 2004, and subsequently decreased in later years (Fig. 33). There was a sudden drop in TP loads in 2011 and in 2017 TP load was 35% lower compared to the respective load in the reference period (1997–2003). The main reason behind the decrease in phosphorus load were improvements in treatment of wastewater originating from point sources. One of the most important achievements was the reconstruction of the main sewer collector in the northern part of St. Petersburg, carried out by Vodokanal between 2008 and 2012), which enabled the closure of sixty-seven direct discharges of untreated waste water to the Neva River. In 2014 99% of wastewater was treated in St. Petersburg and the nitrogen load had decreased by 14,000 t y−1 (60%) and the phosphorus load by 3600 t y−1 (90%) since 1978 (Vodokanal 2015).

The correlation between flow and load was weak (Fig. 34).

The correlation between flow and nutrient export was very weak in the Neva River. According to the Russian experts concentrations in the Neva are highly affected by inputs coming from Ladoga Lake, but the weak correlation between flow and load can partly be explained by the changes in concentrations at the river mouth.

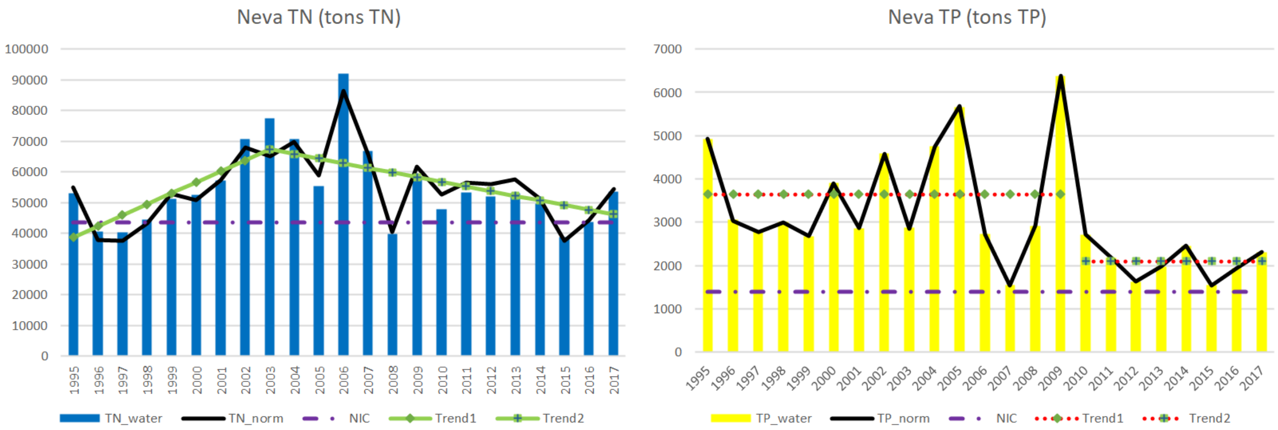


Figure 33. Total N (blue bars) and total P export (yellow bars) by the Neva River from 1995 to 2017. The black lines are showing flow-normalised nutrient export and the green lines the trend in the flow-normalised export. Solid lines indicate statistically significant trend and dashed lines non-significant trend.

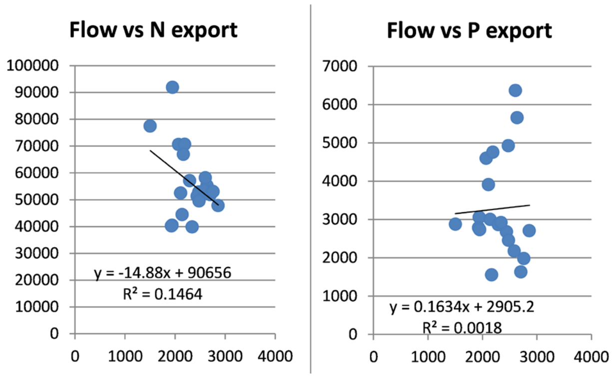


Figure 34. The relationship between water flow and NTOT & PTOT export.