HELCOM

Inputs of nutrients

INDICATOR TYPE: Core
INDICATOR CATEGORY: Pressure
BSAP SEGMENT: Eutrophication
MSFD CRITERIA: D5C1

Inputs of nutrients (nitrogen and phosphorus) to the sub-basins 1995-2023

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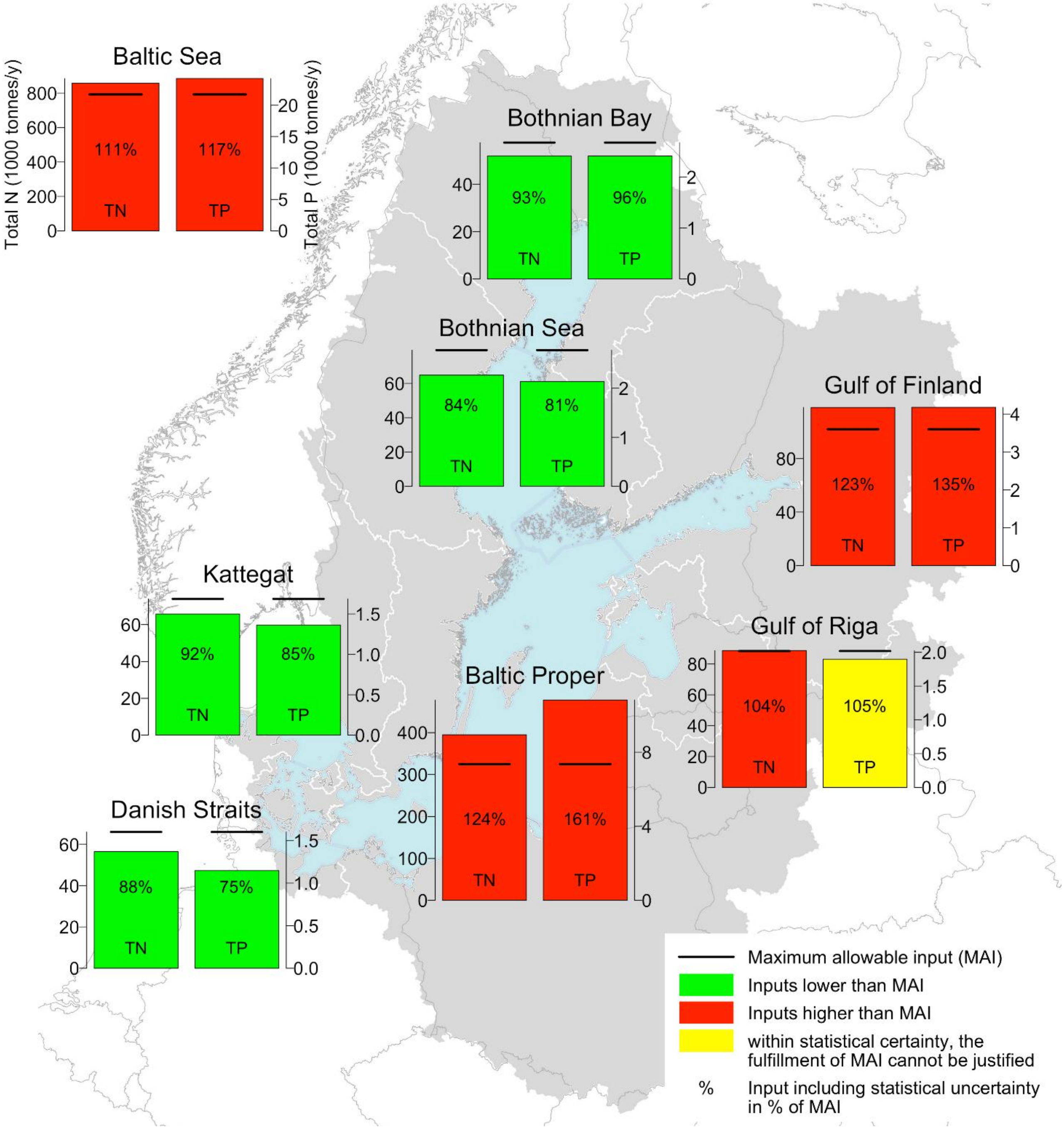
1 Key message

The maximum allowable inputs (MAI) indicate the level of annual inputs of water- and airborne nitrogen and phosphorus to Baltic Sea sub-basins for which a scientific basis exists that this input scenario supports the achievement of the good environmental status for eutrophication.

A significant reduction of nutrient inputs has been achieved for the whole Baltic Sea by 2023. This assessment shows that the normalized total input of nitrogen[1] was reduced by 11% and phosphorus by 33% between the reference period (1997-2003) and 2023 (see Key message table 1 and Results figure 1, section 4). The corresponding reductions by 2022 were 11% for total inputs of nitrogen and 32% for total phosphorus. MAI of nitrogen and phosphorus was fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat by 2023 (Key message figures 1 and Results tables 2a and 2b). In the Gulf of Riga, MAI was not fulfilled for nitrogen, and the fulfilment of MAI for phosphorus cannot be judged taking the statistical uncertainty on inputs into account. In the Baltic Proper and the Gulf of Finland, the MAI was not fulfilled for either total nitrogen or total phosphorus.

[1] Total inputs of nitrogen and phosphorus are the sum of the respective waterborne inputs (which consists of riverine inputs and direct inputs (point sources discharging directly to the sea), respectively) and airborne inputs. Nitrogen and phosphorus inputs include all fractions of these nutrients (dissolved, particulate, inorganic and organic).



Key message figure 1. Total input of nitrogen and phosphorus to each Baltic Sea sub-basin (with use of Pollution Load Compilation (PLC) divisions, see Methodology Section 9) and the whole Baltic Sea (BAS). Trend-based estimates of total nitrogen and phosphorus inputs in 2023 (tonnes/y) are compared to the maximum allowable nutrient inputs (MAI t/y, shown as a black line). Green colour indicates that estimated inputs including statistical uncertainty (see Results Tables “2a and 2b) were lower than MAI, red colour indicates that inputs were higher, while yellow indicates that it is not possible to determine whether MAI was fulfilled taking statistical uncertainty into account. The number in the bar indicates the estimated inputs in 2023 including uncertainty as the relative share in percent (%) of the MAI. *Note: the scales on the y-axes differ in the charts.*

Key messages table 1. Statistically significant changes (in %) by 2022 in airborne, waterborne, total nitrogen inputs since the reference period (1997-2003) and the corresponding changes for waterborne and total phosphorus inputs. Statistically significant decrease if the numbers are negative. "-"= no significant changes.

	Changes in airborne N inputs since 1997-2003	Changes in waterborne N inputs since 1997-2003	Changes in total N inputs since 1997-2003	Changes in waterborne P inputs since 1997-2003	Changes in total P inputs since 1997-2003
Bothnian Bay	-38	-15	-18	-18	-17
Bothnian Sea	-37	-19	-26	-28	-24
Baltic Proper	-37	9.3	-9.3	-37	-35
Gulf of Finland	-33	-	-	-49	-48
Gulf of Riga	-34	20	-	-34	-33
Danish Straits	-39	-19	-23	-24	-22
Kattegat	-41	-22	-28	-21	-20
Baltic Sea	-37	-	-11	-35	-33

The structure of the indicator follows the standard template for HELCOM Core indicators describing the relevance of the indicator in chapter 2 and threshold values in chapter 3. Results of the annual data assessment are in chapter 4, confidence of assessment results in chapter 5. Drivers, activities and pressures related to this indicator are introduced in chapter 6. The importance of climate change and other factors for the indicator are described in chapter 7, followed by the conclusions in chapter 8. A description on the methodologies and the assessment is summarized in chapter 9. The assessment data is presented in chapter 10.

1.2 Citation

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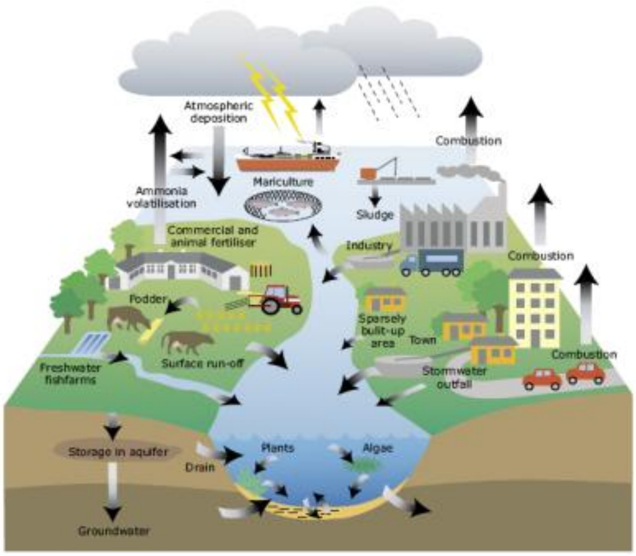
2 Relevance of the indicator

2.1 Ecological relevance

Eutrophication in the Baltic Sea is to a large extent driven by excessive inputs of the nutrients nitrogen and phosphorus due to accelerating anthropogenic activities since the 20th century. Nutrient over-enrichment (or eutrophication) and/or changes in nutrient ratios in the aquatic environment cause elevated levels of algal and plant biomass, increased turbidity, oxygen depletion in bottom waters, changes in species composition and nuisance blooms of algae. In turn, such alterations can influence broader ecosystem functionality and structure, for example altered composition and energy flows in food webs.

The majority of nutrient inputs to the Baltic Sea originate from anthropogenic activities on land and at sea. Waterborne inputs enter the sea via riverine inputs and direct discharges from coastal areas. The main sources of waterborne inputs are point sources (e.g. wastewater treatment plants, industries and aquaculture), diffuse sources (agriculture, managed forestry, scattered dwellings, stormwater overflows etc.) and natural background sources. The main sectors contributing to atmospheric inputs are combustion in energy production and industry as well as transportation for oxidized nitrogen, and agriculture for reduced nitrogen. A large proportion of atmospheric inputs originate from distant sources outside the Baltic Sea region. Emissions from shipping in the Baltic Sea and North Sea also contribute significantly to atmospheric inputs of nitrogen. In addition, excess nutrients stored in bottom sediments can enter the water column and enhance primary production of plants (Relevance figure 1).



Relevance figure 1. Different sources of nutrients to the sea and examples of nitrogen and phosphorus cycles. The flow related to ammonia volatilization shown in the figure applies only to nitrogen. In this indicator, also combustion and atmospheric deposition refer to nitrogen only. Emissions of phosphorus to the atmosphere by dust from soils are not shown in the figure and are not subject to the presented assessment. (Source: Ærtebjerg et al. 2003)

Information on the annual quantity of nutrient inputs is of key importance to follow up the long-term changes in the nutrient inputs to the Baltic Sea. This information, together with information from land-based sources and nutrient retention within the catchment, is also crucial for determining the importance of different sources of nutrients for the pollution of the Baltic Sea as well as for assessing the effectiveness of measures undertaken to reduce the pollution inputs. Quantified input data is a prerequisite to interpret, evaluate and predict the state of the marine environment and related changes in the open sea and coastal waters.

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State indicators linked to the pressure of nutrient inputs

The response in the eutrophication status from changes in nutrient inputs may be considerably slow. Model simulations indicate that it could take half a century or more after nutrient inputs have reached the MAI until the environmental targets may be achieved (Gustafsson, B.G & Mörth, C.M, document 2-43 HOD 41-2013). However, the simulations indicate further that significant improvements could be expected after 1-2 decades. It should be noted that determination of these timescales is regarded as more uncertain than the ultimate long-term state because of unexpected non-linear responses of, e.g., phosphorus to improved oxygen concentrations. In coastal areas one can expect faster responses, especially when significant direct point sources are removed. This is probably also the case for the eastern part of the Gulf of Finland.

The effect of changes in nutrient inputs on the core HELCOM eutrophication status indicators dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), chlorophyll-*a*, Secchi depth and oxygen debt are thoroughly evaluated in Gustafsson, B.G & Mörth, C.M, document 2-43 HOD 41-2013.

Relevant core indicators on eutrophication status can be found on the HELCOM Indicators website:

Total nitrogen

Total phosphorus Water transparency

Chlorophyll-a

Oxygen debt

Cyanobacterial blooms (pre-core)

Phytoplankton

Information on other relevant supporting parameters (Baltic Sea Environment Factsheets):

Cyanobacteria biomass 1990-2022

Impacts of invasive phytoplankton species on the Baltic Sea ecosystem (updated 2009)

Atmospheric nitrogen deposition to the Baltic Sea area in 1990-2023

Nitrogen emissions to the air in the Baltic Sea area in 1990-2023

Spatial distribution of winter nutrient pool (updated 2017)

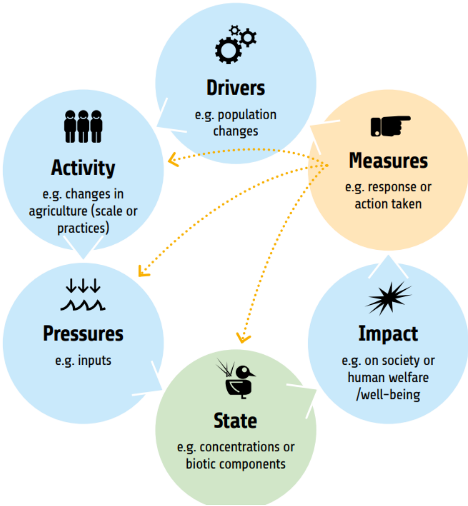
Unusual phytoplankton event (updated 2010)

Bacterioplankton growth (updated 2024)

2.2 Policy relevance

As a follow-up to the original Baltic Sea Action Plan (2007), a revised HELCOM nutrient reduction scheme was adopted in the 2013 HELCOM Ministerial Declaration (HELCOM 2013a) in which reduction requirements for nitrogen inputs to the Baltic Proper, Gulf of Finland and Kattegat and for phosphorus inputs to the Baltic Proper, Gulf of Finland and Gulf of Riga were set. The HELCOM nutrient reduction scheme defines maximum allowable inputs (MAI) of nutrients, which indicate the maximum level of inputs of water- and airborne nitrogen and phosphorus to Baltic Sea sub-basins that can be allowed in order to achieve the good status in terms of eutrophication. This core indicator presents progress in the different Baltic Sea sub-basins towards these MAI levels. The updated Baltic Sea Action Plan 2021 reconfirmed the MAIs and their achievement for all sub-basins as the key prerequisite for achieving the ecological objective of a Baltic Sea unaffected by eutrophication and contains measures to follow-up and assess the progress towards MAI (HELCOM 2021).

The progress of countries in reaching their country-wise allocation of nutrient reduction targets (formerly known as CART) is assessed separately in a follow-up system based on nutrient input ceilings (NIC) per country per Baltic Sea sub-basin, as included in the updated BSAP 2021 (HELCOM, 2021). Relevance figure 2 illustrates how the nutrient reduction scheme fits into the HELCOM causal framework of drivers, activity, pressure, state, impact and measures (DAPSIM), providing a conceptual management framework through which key elements can be detailed and evaluated. Setting individual indicators (or components of indicators) within a causal framework supports the BSAP by providing additional information that can facilitate the follow-up on how actions and measures impact on other socioeconomic and state variables (HELCOM 2020).



Relevance figure 2. The conceptual approach for a HELCOM causal framework – DAPSIM with drivers, activities, pressures, state, impact and measures. Here the quantitative targets of MAI and Nutrient Input Ceilings country by sub-basin are within the Pressures.

Reducing the effects of human-induced eutrophication is the stated goal of Descriptor 5 in the EU Marine Strategy Framework Directive (MSFD). The indicator is an important part in following up the effectiveness of the measures taken to achieve good environmental status (GES) under this Descriptor. Inputs of nutrients to the Baltic Sea marine environment have an effect on the nutrient levels under Descriptor 5 Criterion 1. It is important to note that this pressure indicator on inputs of nutrients relates to HELCOM eutrophication state core indicators. More information on this is provided in the section below on Environmental Targets and progress towards GES.

The information provided in this pressure indicator also supports follow-up of the effectiveness of measures implemented under the following agreements, as each of them addresses reduction in nutrient inputs in some way or another: EU Nitrates Directive; EU Urban Waste-Water Treatment Directive; EU Industrial Emissions Directive, IED; EU Water Framework Directive, WFD; the Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone under UNECE Convention on Long-range Transboundary Air pollution (CLRTAP); EU NEC Directive; IMO designation of the Baltic Sea as a ”special area” for passenger ships under MARPOL (International Convention for the Prevention of Pollution from Ships) Annex IV (on sewage from ships); EC Directive on port reception facilities; and the Application of the Baltic Sea NOx emission control area (NECA).

An overview of key policy aspects or direct relevance is provided in Relevance Table 1.

Relevance Table 1. Overview of key policy relevance for this indicator.

	Baltic Sea Action Plan (BSAP)	**Marine Strategy Framework Directive (MSFD)**
Fundamental link	Segment: "Eutrophication" Goal: "Baltic Sea unaffected by eutrophication" • Ecological objectives: "Concentrations of nutrients close to natural levels", "Clear waters", "Natural level of algal blooms", "Natural distribution and occurrence of plants and animals", and "Natural oxygen levels". • Management objective: "Minimize inputs of nutrients from human activities" Segment: Sea-based activities • Management objective: "Minimize the input of nutrients, hazardous substances and litter from sea-based activities" • The achievement of regional nutrient input targets – Maximum Allowable Inputs (MAI) and Nutrient Input Ceilings (NIC) – for all sub-basins, as identified in this BSAP, is the key prerequisite for achieving the ecological objectives.	Descriptor 5 Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters - Macrofaunal communities of benthic habitats. • Criteria 1 Nutrient concentrations are not at levels that indicate adverse eutrophication effects. The threshold values are as follows: (a) in coastal waters, the values set in accordance with Directive 2000/60/EC; (b) beyond coastal waters, values consistent with those for coastal waters under Directive 2000/60/EC. Member States shall establish those values through regional or subregional cooperation • Feature – Eutrophication. • Element of the feature assessed – Transparency.
Complementary link		Descriptor 5 Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters - Macrofaunal communities of benthic habitats. • Criteria 2 Chlorophyll a concentrations are not at levels that indicate adverse effects of nutrient enrichment. The threshold values are as follows: (a) in coastal waters, the values set in accordance with Directive 2000/60/EC; (b) beyond coastal waters, values consistent with those for coastal waters under Directive 2000/60/EC. Member States shall establish those values through regional or subregional cooperation. • Criteria 3 The number, spatial extent and duration of harmful algal bloom events

		are not at levels that indicate adverse effects of nutrient enrichment. • Criteria 4 The photic limit (transparency) of the water column is not reduced, due to increases in suspended algae, to a level that indicates adverse effects of nutrient enrichment. The threshold values are as follows: (a) in coastal waters, the values set in accordance with Directive 2000/60/EC; (b) beyond coastal waters, values consistent with those for coastal waters under Directive 2000/60/EC. Member States shall establish those values through regional or subregional cooperation. • Feature – Eutrophication. • Element of the feature assessed – Transparency. • Criterion 5 The concentration of dissolved oxygen is not reduced, due to nutrient enrichment, to levels that indicate adverse effects on benthic habitats (including on associated biota and mobile species) or other eutrophication effects. The threshold values are as follows: in coastal waters, the values set in accordance with Directive 2000/60/EC; beyond coastal waters, values consistent with those for coastal waters under Directive 2000/60/EC. Member States shall establish those values through regional or subregional cooperation. • Feature – Eutrophication. • Element of the feature assessed – Dissolved oxygen.
Other relevant legislation:	EU Nitrates Directive; EU Urban Waste-Water Treatment Directive; Industrial Emissions Directive (IED), Water Framework Directive, WFD; the Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone under UNECE Convention on Long-range Transboundary Air pollution (CLRTAP); EU NEC Directive; Water Code of Russian Federation; Federal Act on the internal maritime waters, territorial sea and contiguous zone of the Russian Federation; IMO designated the Baltic Sea as a ”special area” for passenger ships under MARPOL (International Convention for the Prevention of Pollution from Ships) Annex IV (on sewage from ships); EC Directive on port reception facilities; NOx emission control areas (NECA) in the Baltic and North seas designated by IMO. UN Sustainable Development Goal 14 (Conserve and sustainably use the oceans, seas and marine resources for sustainable development) is most clearly relevant, though SDG 12 (Ensure sustainable consumption and production patterns) and 13 (Take urgent action to combat climate change and its impacts) also have relevance.	

2.3 Relevance for other assessments

Human activities affecting the status of the marine environment are assessed using several indicators and spatial data on pressures. Each indicator focuses on one important aspect of the complex issue. In addition to an indicator-based evaluation of the nutrient inputs to the marine environment, this indicator also contributes to the holistic assessment of the Baltic Sea (the State of the Baltic Sea report, HOLAS).

3 Threshold values

Environmental Target and progress towards good status

The environmental targets for nutrient inputs are the maximum allowable inputs (MAI) of the HELCOM nutrient reduction scheme (Thresholds table 1), as confirmed in 2021 HELCOM Baltic Sea Action Plan (BSAP) (BSAP 2021, page 22). The MAI indicate the maximal level of annual inputs of water- and airborne nitrogen and phosphorus to Baltic Sea sub-basins that can be allowed while still achieving good status in terms of eutrophication.

A provisional nutrient reduction scheme was adopted in the HELCOM Baltic Sea Action Plan (HELCOM 2007). The presented MAI was revised based on an improved scientific basis and models and were adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a). The MAI of 2013 has been incorporated in the updated BSAP that was adopted in 2021 (HELCOM, 2021).

Thresholds table 1. Maximum allowable annual inputs (MAI) of nitrogen and phosphorus to the Baltic Sea sub-basins.

Baltic Sea Sub-basin	Maximum allowable annual nitrogen inputs (tonnes)	Maximum allowable annual phosphorus inputs (tonnes)
Bothnian Bay	57 622	2 675
Bothnian Sea	79 372	2 773
Baltic Proper	325 000	7 360
Gulf of Finland	101 800	3 600
Gulf of Riga	88 417	2 020
Danish Straits	65 998	1 601
Kattegat	74 000	1 687
Baltic Sea	**792 209**	**21 716**

3.1 Setting the threshold value(s) (method/reference/logic)

MAI was calculated by the Baltic Nest institute (BNI), Sweden, using the coupled physical-biogeochemical model BALTSEM (Gustafsson, B.G & Mörth, C.M, 2013). Obtaining MAI is formally an optimization problem: finding the highest possible input levels (targets) that will still satisfy the given eutrophication status (e.g. threshold values for eutrophication status indicators).

The basin-wise MAI were obtained by satisfying all eutrophication targets in all sub-basins, taking into account ecological relevance and model accuracy. More details are provided in Gustafsson, B.G & Mörth, C.M, 2013 (document 2-43 HOD 41-2013).

For sub-basins without additional reduction requirements, the 1997-2003 averaged normalized inputs obtained within the PLC 5.5 project are used as MAI. For more information, see HELCOM 2013b.

The uncertainty in the determination of MAI can be assigned to three sources: uncertainty in the eutrophication targets, uncertainties associated with model shortcomings and uncertainties in the input data to the calculation. The confidence in the eutrophication targets has been classified as moderate or high, depending on the parameter (HELCOM 2013c). It is straightforward but laborious to explore how MAI varies with changes in target values from the pressure-response relationships (i.e., the model derived change in target values for a given change in nutrient inputs). The laborious aspect arises from the numerous combinations of uncertainty that can arise if many indicator values and sub-basins are simultaneously considered. However, the impression is that the nitrogen target causes the greatest uncertainty in the determination of MAI for most sub-basins. Reasons are that in most cases there are no, or only few, trustworthy measurements to indicate the pre-eutrophied situation in the Baltic and also because the relationship between nitrogen input and concentrations in sea waters is rather weak in sub-basins featuring hypoxia and strong nitrogen limitations (i.e. the Baltic Proper and the Gulf of Finland) because of large internal feedback from nitrogen fixation and denitrification.

When calculating MAI, attempts have been made to take into account biases in BALTSEM by discarding indicators in sub-basins where they are not adequately modelled, and by raising a concern of whether MAI is really trustworthy because of model deficiency/bias.

Note: both MAI and nutrient input ceilings (NIC) calculations are affected by the input data to the model. If input data are inconsistent, it may cause over- or underestimation of MAI and NIC, and thus an unfair distribution of reduction requirements between countries.

4 Results and discussion

The results of the indicator evaluation that underly the key message map and information are provided below.

4.1 Status assessment

Weather in 2023 in the Baltic Sea catchment

Particularly precipitation and temperature have an impact on the amount and distribution of flow to the Baltic Sea from different parts of the catchment, and thereby on inputs of nitrogen and phosphorus. Overall rainfall above average will result in higher-than-average flow and higher inputs of riverine total nitrogen and total phosphorus than with low rainfall and flow. High accumulation of snow on the surface combined with high temperature and rainfall can result in a strong spring flood and high nutrient loads in rivers. Heavy rainfall can also result in soil surface erosion. When soils in autumn and winter are saturated, precipitation will tend to reach quickly into surface waters, while rain can be absorbed in dry soils and vegetation during spring and summer. The type, intensity, amount and distribution of precipitation during the year is therefore of key importance for flow and input of nutrients to the Baltic Sea.

The annual BSEFS on waterborne nitrogen and phosphorus inputs and waterflow to the Baltic Sea 1995-2023 (Svendsen and Gustafsson, 2025) include maps from Copernicus on precipitation and deviation from average values in 2023 and detailed precipitation patterns are provided. The annual precipitation in 2023 was higher (typical 10-20%) than normal (1991-2020) in most of the Baltic Sea catchment areas: Denmark, Germany, biggest part of Estonia, Finland, Latvia, Poland and the southern half of Sweden. In the north of Sweden, northern part of Finland, north of Poland and Lithuania the annual precipitation was below or close to average. Particularly Denmark, Germany and the southwestern part of Sweden had very high precipitation.

Winter (December 2022-February 2023) was 5-20 % wetter than normal in most part of the Baltic Sea catchment areas, and particularly in Denmark and southwestern part of Russia. Spring was drier than normal (10-40 %) for most of the catchments in the Baltic States, Germany, northern part of Finland, most of Poland, Russia and Sweden, but wetter (5-15%) in Denmark, part of southern and mid-Finland and southwestern Sweden. Summer 2023 precipitation was drier or close to normal (5-15%) in most parts of Estonia, southern part of Lavia, parts of Lithuania, Germany, main part of Poland, Russia and in the northern parts of Sweden. Precipitation was higher or very much higher (up to more than 40% over the long-term average) in Denmark, southern part of Sweden, southwestern and central part of Finland, northern part of Lativa and some central part of Poland. Autumn was wetter or a lot wetter (10-35%) than normal in Denmark, Estonia, most of Germany, Finland, Poland Russia and some parts of central and northern part of Sweden, but close to normal or drier (5-20%) in southern part of Latvia, parts of Lithuania and southern and some central parts of Sweden.

- Denmark broke precipitation records for January and July, as well as the annual precipitation record with 28% higher precipitation than the long-term average (1991-2020). Heavy rain falls resulted in high flow rates from Denmark: to Kattegat 27% higher (precipitation 26% higher) than long term average, 20% higher (precipitation 24% higher) to Danish Straits but only 7% higher to Baltic Proper (precipitation 15% higher). The very rainy conditions led to widespread flooding in river valleys and further on agricultural areas during several months, and it affected harvest in late summer and autumn 2023. It also affected runoff conditions and nitrogen loads in 2024.

- In Estonia, the annual flow was 6% higher that the long-term average (defined for Estonia as 1992-2022).
- For Finland, the higher than long-term average precipitation on the most of Finnish catchment to the Baltic Sea was also reflected in the flow: It was higher than long-term average to Bothnian Bay (11%), Bothnian Sea (30%), Archipelago Sea (23%) and Gulf of Finland (17%).
- Germany: Despite precipitation higher than long-term average the estimated runoff was about 24% lower than the long-term average (1994-2022). In 2022, there was low precipitation affecting the flow in 2023.
- Latvia had higher than long term-average precipitation in January and February 2023 resulting in high flow and nitrogen leaching from most catchments.
- In Lithuania some part of the catchment received higher than average precipitation and other areas lower than average precipitation, resulting in over average annual flow for some rivers and under for some others. Overall, the flow to Baltic Proper from Lithuania in 2023 was close to average of 1995-2020 while it was 37% higher than the average to Gulf of Riga.
- In Poland annual flow was 2023 about 7 % below long-term average (1995-2022) but nearly 16% higher than the preceding 5 years (2018-2022).
- The rainfall in Sweden was much above long-term average in the southern parts, but close to it in the northern part. The early part of 2023, and early late summer and autumn were wetter than the long-term average, but May and June were very dry. Early autumn snow stayed for the remainder of 2023.

Actual airborne and waterborne inputs and flow in 2023

In 2023, the annual flow to the Baltic Sea was higher than average (7.9 % over the average of 1995-2022, Result table 1). The flow was higher than average to five sub-basins: Gulf of Riga (28%), Kattegat (25%), Danish Straits (17%), Bothnian Sea (14%), and Bothnian Bay (8.0%), and close to average to Baltic Proper (-2.6%) and Gulf of Finland (1.5%).

Actual total input of nitrogen in 2023 was about 879,000 tonnes, which is 11 % higher than the average of the 10 previous years (2013-2022). The nitrogen inputs in 2023 to Gulf of Riga were record high during the whole period 1995-2023 and 54% higher than average of 2013-2022. Normalized total input of nitrogen to the Baltic Sea in 2023 was about 840,000 tonnes and 1.2% lower than average of 2013-2022. Normalized annual total nitrogen inputs in 2023 to Bothnian Bay, Gulf of Finland, Danish Straits and Kattegat were the second lowest, and to Bothnian Sea fourth and Baltic Sea fifth lowest, respectively during 1995-2023, but to Gulf of Riga the third highest.

Actual total phosphorus inputs were about 23,500 tonnes and the fourth lowest yearly inputs during 1995-2023.The phosphorus inputs in 2023 was the second lowest Gulf of Finland, third lowest to Baltic Proper, and fourth lowest to the Baltic Sea during 1995-2023, but ninth highest to Kattegat. Normalized total input of phosphorus to the Baltic Sea in 2023 was about 23,000 tonnes and 17% lower than average of 2013-2022. Normalized total inputs of phosphorus in 2023 were the lowest during the whole period 1995-2023 to Baltic Sea, Baltic Proper, Gulf of Finland, and between fourth and seventh lowest for the remaining sub-basins.

Input in 2023 of normalized atmospheric total nitrogen was the lowest during the whole period 1995-2023 to all Baltic Sea sub-basins, and 14 % lower to the Baltic Sea than average of 2013-2022. Actual total atmospheric deposition of nitrogen in 2023 was the second lowest to most Baltic Sea sub-basins and to the Baltic Sea during 1995-2023, but only third lowest to Danish Straits, fourth lowest to Gulf of Riga and nineth lowest to Gulf of Finland.

Atmospheric deposition constituted about 22% of total nitrogen inputs in 2023, the main pathway for nitrogen inputs to the Baltic Sea was via rivers (75%) (Results table 1 and Results figure 3). The share of direct inputs (point sources discharging directly into the sea) of nitrogen was low and on average only about 3%. Atmospheric inputs contributed about 9% of total phosphorus inputs (Results table 1 and Results figure 3). The main pathway for total phosphorus was also via rivers (87%). Direct inputs of phosphorus constituted on average less than 5% but had a significantly higher share to some sub-basins, particularly to Danish Straits (18%).

Results table 1. Annual average water flows ($m^3 s^{-1}$) as well as actual annual waterborne and airborne inputs of phosphorus and nitrogen (tonnes) to the Baltic Sea sub-basins in 2023. Average flows 1995-2022 and the deviations from these in 2023 are shown for comparison.

Sub-basin	Average flow 1995-2022 ($m^3 s^{-1}$)	Flow 2023 ($m^3 s^{-1}$)	Flow deviation average %	Nitrogen 2023 (tonnes)			Phosphorus 2023 (tonnes)		
				Waterborne	Airborne	Total	Waterborne	Airborne	Total
Bothnian Bay	3,460	3,737	8.0	51,646	6,440	58,086	2,545	181	2,727
Bothnian Sea	2,912	3,308	13.6	57,066	21,706	78,772	2,152	394	2,546
Baltic Proper	3,367	3,280	-2.6	278,745	101,823	380,568	8,099	1,046	9,146
Gulf of Finland	3,539	3,592	1.5	91,904	13,222	105,126	3,289	150	3,439
Gulf of Riga	1,045	1,340	28.3	113,419	8,159	121,578	2,525	93	2,618
Danish Straits	214	251	17.4	39,000	20,761	59,762	1,189	105	1,293
Kattegat	1,064	1,329	24.9	57,643	17,221	74,864	1,599	118	1,718
Baltic Sea	**15,601**	**16,837**	7.9	**689,424**	**189,332**	**878,756**	**21,399**	**2,088**	**23,487**

Fulfilment of MAI in 2023 and progress since the reference period (1997-2003)

According to the revised HELCOM nutrient reduction scheme adopted in the 2013

HELCOM Ministerial Declaration (HELCOM 2013a), reduction requirements were set for nitrogen inputs to the Baltic Proper, Gulf of Finland and Kattegat and for phosphorus inputs to Baltic Proper, Gulf of Finland and Gulf of Riga.

The Kattegat is the only sub-basin out of three with updated 2021 BSAP reduction targets for nitrogen inputs (i.e. Baltic Proper, Gulf of Finland and Kattegat) where the input was significantly below MAI in 2023 (Key messages figure 1 and Results table 2a). However, from the reference period (1997-2003) to 2023, a statistically significant[2] reduction of nitrogen input has been achieved to all sub-basins except the Gulf of Finland and Gulf of Riga, where no significant reduction has been observed (Results figure 1) using the statistical methodology summarized in Assessment protocol table 1 in chapter 9. The highest observed input reduction was to Kattegat and Bothnian Sea (both 26 %) and Danish Straits (23%), and the lowest to the Baltic Proper (11%) (Results figure 1). Nitrogen inputs to the entire Baltic Sea have been reduced by 11% since the reference period.

None of the three sub-basins for which updated 2021 BSAP reduction targets for phosphorus inputs were set (Baltic Proper, Gulf of Finland and Gulf of Riga), fulfilled the requirements in 2023 (Key message figure 1 and Results table 2b). However, statistically significant reductions have been achieved in all sub-basins since the reference period. The highest input reductions since the reference period (1997-2003) were achieved in the Gulf of Finland (48%), Baltic Proper (35%), and Gulf of Riga (33%) (Results figure 1). Phosphorus inputs to the entire Baltic Sea have been reduced by 33% since the reference period, and nearly 75% of this reduction is due to reduced phosphorus inputs to Baltic Proper and to the Gulf of Finland.

Trend estimated airborne and waterborne nitrogen inputs including uncertainties are also assessed for the Baltic Sea and its sub-basins and compared with the trend estimated total nitrogen inputs including uncertainties in Results table 3.

Results table 2a and b. The trend-based estimates for normalized annual inputs of (a) nitrogen and (b) phosphorus during 2023.

The table also contains data on statistical uncertainty, the remaining reduction needed to reach MAI and inputs in 2023 including statistical uncertainty in percentages of MAI. Classification of achieving MAI is given in colours: green=MAI fulfilled, yellow= fulfilment is not determined due to statistical uncertainty, and red=MAI not fulfilled. (Units in columns 2-5: tonnes/y). NOTE: *For consistency with MAI no rounding (to tenth, hundreds or thousands) has been performed in the indicator***Table 2a.**

[2] Using a linear regression model including check for breakpoints as described in chapter 9

Baltic Sea Sub-basin	MAI*	N input 2022	Statistical uncertainty 2022	N input including statistical uncertainty 2022	Exceedance of MAI in 2022	Input 2022 including statistical uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay	57,622	52,298	1,566	53,864		93	
Bothnian Sea	79,372	64,716	2,073	66,790		84	
Baltic Proper (BAP)	325,000	393,286	7,616	400,902	75,902	123	
Gulf of Finland	101,800	121,211	7,420	128,631	26,831	126	
Gulf of Riga (GUR)	88,417	87,808	3,080	90,887	2,470	103	
Danish Straits (DS)	65,998	56,048	1,744	57,792		88	
Kattegat (KAT)	74,000	63,821	2,707	66,528		90	
Baltic Sea (BAS)	**792,209**	**856,569**	**19,538**	**876,106**	**83,897**	**111**	

Table 2b.

Baltic Sea sub-basin	MAI*	TP input 2023	Statistical uncertainty 2023	TP input including statistical uncertainty 2023	Exceedance of MAI in 2023	Input 2023 including statistical uncertainty in % of MAI	Classification of achieved reduction
Bothnian Bay	2,675	2,412	160	2,572		96	
Bothnian Sea	2,773	2,135	103	2,238		81	
Baltic Proper	7,360	10,817	1,045	11,862	4,502	161	
Gulf of Finland	3,600	4,179	683	4,862	1,262	135	
Gulf of Riga (GUR)	2,020	1,899	226	2,125	105	105	
Danish Straits	1,601	1,147	56	1,203		75	
Kattegat (KAT)	1,687	1,364	66	1,429		85	
Baltic Sea (BAS)	21,716	24,266	1,215	25,481	3,765	117	

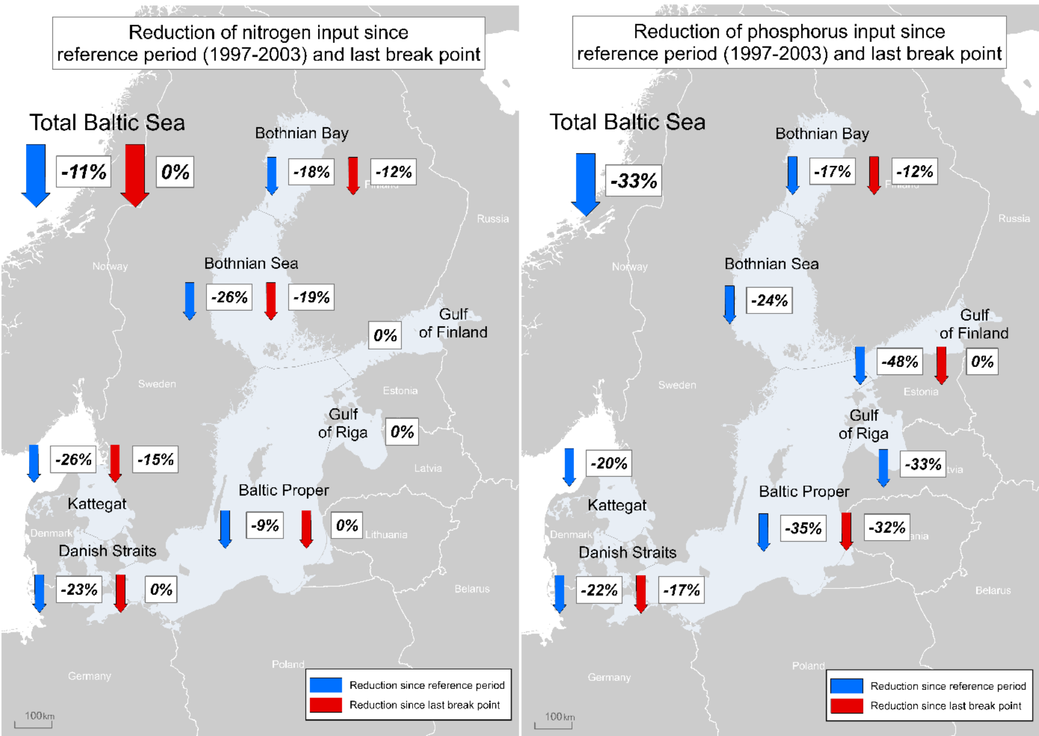
*As adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a) and in BSAP update 2021 (HELCOM, 2021)

Results table 3. Trend estimated airborne, waterborne and total nitrogen inputs to sub-basin and to the Baltic Sea and sub-basins in 2022. The estimates include uncertainty on the trend estimated inputs.

	Nitrogen inputs in 2023 (tonnes)		
	Airborne	Waterborne	Total
Bothnian Bay	6,334	47,048	53,445
Bothnian Sea	20,425	46,273	66,816
Baltic Proper	103,400	310,912	402,156
Gulf of Finland	11,909	112,471	125,194
Gulf of Riga	7,826	99,057	91,874
Danish Straits	19,323	35,663	58,214
Kattegat	17,038	50,356	68,390

Baltic Sea	**186,185**	**668,259**	**875,811**

Compared to the first evaluation of MAI fulfilment (Svendsen et al. 2015) in 2016, EMEP (European Monitoring and Evaluation Programme) revised the modelled nitrogen air deposition to the Baltic Sea for 1995-2012. This resulted in an increase of the annual deposition to the Baltic Sea from 16 to 23%. The increase of annual nitrogen deposition to the individual sub-basins was between 9 and 27%. In the following, the EMEP deposition model was updated after the second MAI assessment (HELCOM, 2018). The update mainly concerned changes of the deposition grid resolution from 50km*50km to 0.1°*0.1° (approx. 11km*6km grid cells in the Baltic Sea). The higher resolution was applied for computation of the annual nitrogen deposition 2000-2017, and for the present MAI assessment 1995-2023 (Gauss et al., 2025). Also, the whole time series of nitrogen emission data is updated annually, and now emission data for 1990-1994 was also available. For the years since 2000, data from FMI on shipping emissions have replaced former ship emission data in the deposition calculation. The updates of the model, revised reported emission data and the use of meteorological data in the normalization procedure (section "Airborne Inputs" under chapter "Data and updating") resulted in markedly changed deposition data compared to the previous reporting. Deposition on the Baltic Sea in the reference period (1997-2003) was 294 000 tonnes nitrogen in the latest EMEP estimate, compared to 227 000 tonnes nitrogen previously estimated, or 29% higher than calculated for 2013. The nitrogen deposition in the reference period showed the highest change to Kattegat (40%), Gulf of Finland (32%) and the lowest in the Gulf of Riga (16%).



Results figure 1. Significant reductions of total annual inputs of nitrogen (left) and phosphorus (right) achieved in 2023 (in %) since the reference period 1997-2003 (blue arrow) and recent changes (red arrow), where recent changes are significant changes since the last breakpoint of the timeseries. The annual inputs in 2023 and in the reference period (1997-2003) were calculated using normalized annual data. The arrows indicate decreasing (↓) inputs, and only significant changes are shown. Year with the breakpoint is in results tables 3a and 3b, respectively.

Changes in total inputs of nitrogen and phosphorus since the reference period are calculated based on the average normalized inputs in the reference period and the estimated inputs in 2023, resulting from the analysis of long-term trends (1995-2023) (Larsen & Svendsen, 2021). Based on the updated modelled annual nitrogen deposition in 2023 there was a significant reduction in atmospheric nitrogen deposition since the reference period for all sub-basins. The overall reduction to the Baltic Sea in nitrogen deposition was 37%. For the sub-basins, the reduction was between 33 and 41%, the highest for Kattegat and the lowest for Gulf of Finland and Gulf of Riga (Key message table 1).

Phosphorus deposition on the Baltic Sea is calculated as a fixed annual rate of 5 kg P per km^2 sea surface (see section "9.3 Monitoring methodology" of this indicator) during 1995-2023.

By 2023 reduction in atmospheric nitrogen deposition since the reference period to the Baltic Sea contributes overall more to the reduction in total nitrogen inputs than the corresponding reduction in waterborne nitrogen (Results table 4). For Gulf of Finland and Gulf of Riga there were no significant reductions in the total nitrogen inputs, and there were significant increases for Gulf of Riga (+20%) and Baltic Proper (+9.3%) for the waterborne nitrogen inputs. Only for Bothnian Bay and Kattegat airborne reduction had a share that was lower than 50% of the total reductions in nitrogen inputs, with shares of 33 and 46%, respectively.

Results table 4. Significant reductions in airborne nitrogen deposition, waterborne and total nitrogen inputs (tonnes/y) in 2023, respectively, as compared with the reference period (1997-2003) for the sub-basins of and for the whole Baltic Sea, and the airborne deposition share (%) of the reduction. "-" = no significant trend. 100% = there was no significant reduction in waterborne nitrogen inputs or a significant increase (Baltic Proper). Remark: Significant reductions have been tested separately for airborne, waterborne, and total (airborne + waterborne) TN inputs time series, and therefore sums of significant reductions on airborne and waterborne inputs will not necessarily add up to the significant reduction of the total nitrogen inputs. Correspondingly, the airborne shares have been scaled according to the reduction of total nitrogen inputs.

TN reductions	BOB	BOS	BAP	GUF	GUR	DS	KAT	BAS
Airborne (tonnes)	3,827	11,908	59,749	5,833	3,942	12,495	11,719	109,469
Waterborne (tonnes)	7,769	10,589	-25,305	-	-15,388	7,969	13,263	-
Total TN inputs (tonnes)	11,558	22,059	43,665	-	-	16,531	25,276	125,978
Airborne reduction in % of total TN input reduction	33	54	100	100	100	76	46	87

4.2 Trends

Normalization is applied to the annual riverine and atmospheric inputs to reduce the impact of inter-annual variations of the inputs caused by weather-induced conditions (primarily variations in precipitation). With normalization, the comparability of the inter-annual inputs increases, facilitating trend detection and identification of effects of undertaken measures in the catchment areas (Larsen & Svendsen, 2021). Without normalization, trends could be masked by large natural annual variation of precipitation and river flow.

When assessing trends in time series of total nitrogen and total phosphorus inputs, of atmospheric nitrogen inputs and of waterborne nitrogen and phosphorus inputs, breakpoints in the trend lines are also identified (Results figure 2a-e). Except for Gulf of Riga, one or two breakpoints were identified evaluating the trends of **total nitrogen inputs**, dividing the time series 1995-2023 into two or three sections (see also Results table 5a). The Baltic Sea and five sub-basins had significant reductions in total inputs of nitrogen since the reference period. Only for three sub-basins, a significant decrease in total nitrogen inputs since the last breakpoint (also called recent changes) could be observed: Bothnian Sea (19% after breakpoint in 2003), Kattegat (15%, 2012), and Bothnian Bay (12%, 2008).

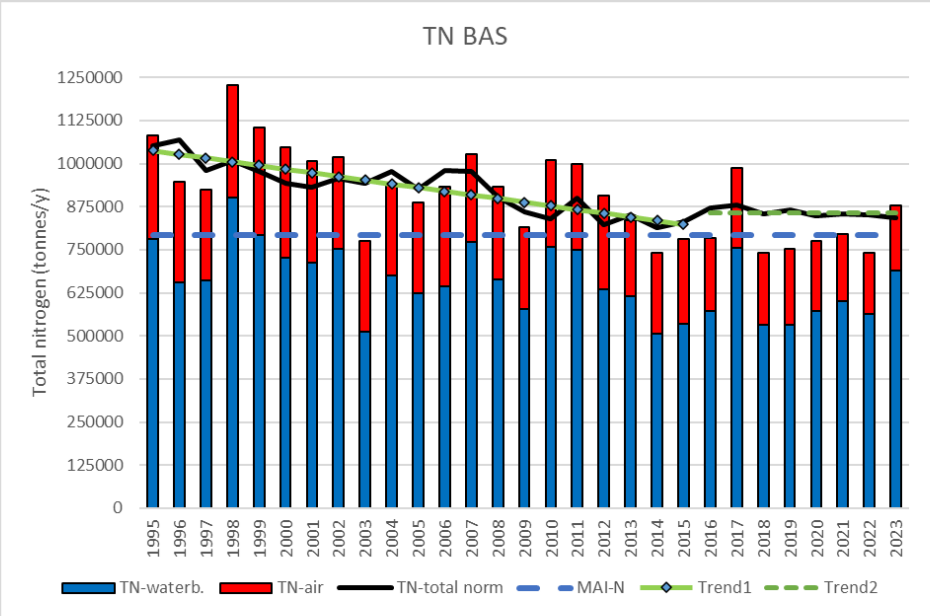
Testing for trends in flows indicated a significant decrease in flow to Baltic Proper (24% 1995 to 2023) and a significant increase in flow to Gulf of Finland (16% 1995-2023). These trends might have an impact on the trend evaluation in the waterborne inputs to the two sub-basins.

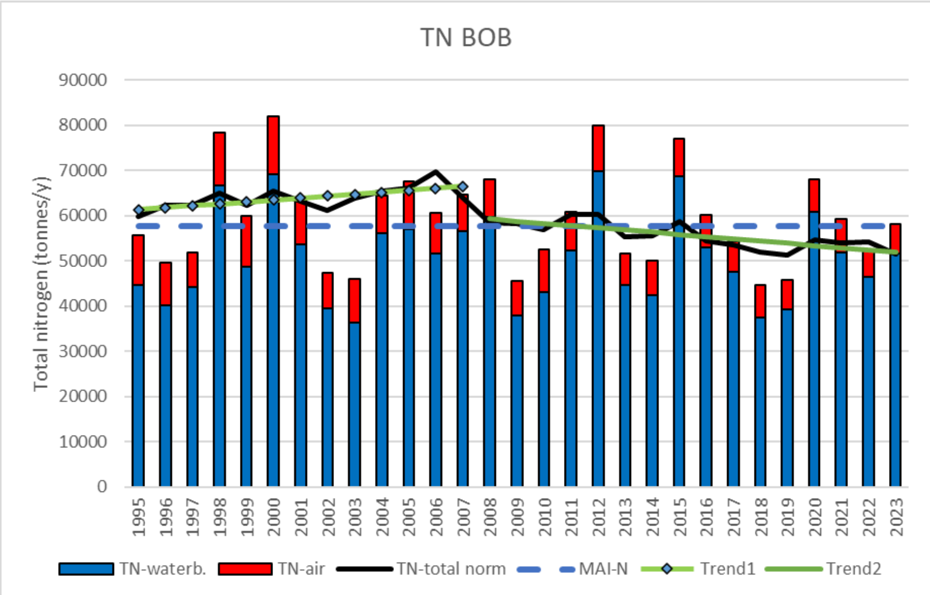
Total phosphorus inputs revealed a statistically significant linear reduction throughout 1995-2023 (without break points, see chapter 9) to the Baltic Sea, Bothnian Sea and Kattegat, and further a statistically significant reduction to all sub-basins since the reference period (Results figure 2b and results table 5c). Breakpoints were detected for four sub-basins: Bothnian Bay, Baltic Proper, Gulf of Finland and Danish Straits, and for three of these sub-basins significant reductions occurred after the breakpoint: Baltic Proper (32%, breakpoint in 2013), Danish Straits (17%, 2000) and Bothnian Bay (12%, 2002) while no trend was detected for Gulf of Finland (0%, 2012) even though total inputs of phosphorus inputs on average were lower 49% after the breakpoint in 2012, but with no trend in inputs before and after the breakpoint. The significant and abrupt reduction in total phosphorus inputs after 2011 for Gulf of Finland is probably connected to rapid changes of inputs due to measures on point sources in the Russian catchment. There was a marked reduction, despite large inter-annual variation preventing efficient flow normalization. This resulted in a high uncertainty in the total inputs of phosphorus to the Gulf of Finland (16% according to Results table 2b). In addition, the Gulf of Riga (12%) and Baltic Proper (10%) had a rather high uncertainty on estimated phosphorus inputs in 2023 compared with the remaining four sub-basins (5-7%). For estimated total inputs of nitrogen in 2023 the uncertainty was also highest in the Gulf of Finland (6%), the uncertainty on inputs in the remaining sub-basins was between 2 and 4% (according to Results table 2a).

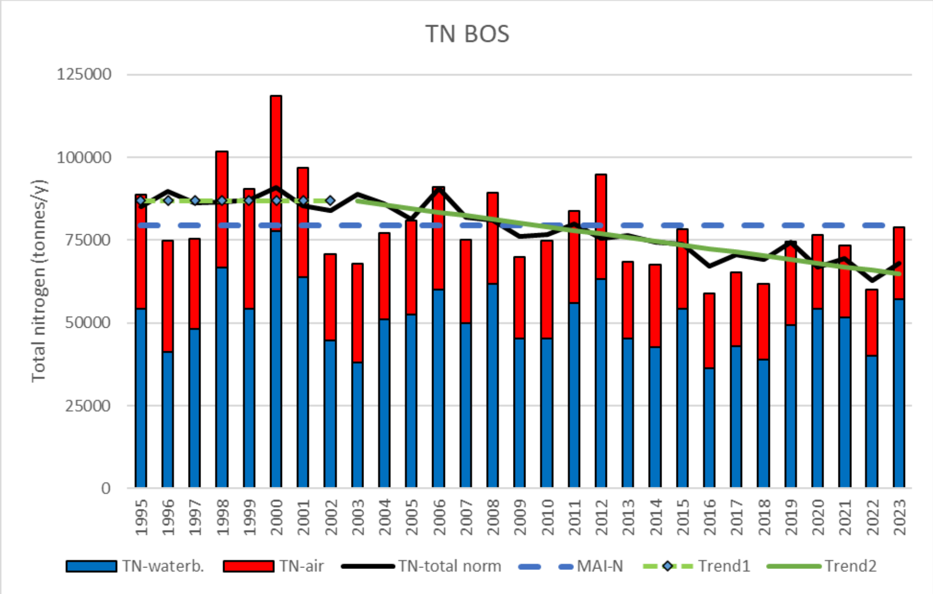
Trend analysis of the normalized timeseries of **airborne inputs of nitrogen** showed a significant decrease to the Baltic Sea and to the seven sub-basins since the reference period (Results table 4 and Results table 5a). For the Baltic Sea and all sub-basins except Danish Straits and Kattegat there are three breakpoints: in 2003, 2009 and 2017; for Danish Straits and Kattegat only two: in 2009 and 2017. For Baltic Sea and all sub-basins there are significant decreases for all segments of the trend line. Recent decreases (after the last breakpoint in 2017) is 17% to the Baltic Sea and ranges between 13% to Gulf of Finland to 21% to Danish Straits corresponding to an annual decrease between 2.2 to 3.4% (Results table 5b).

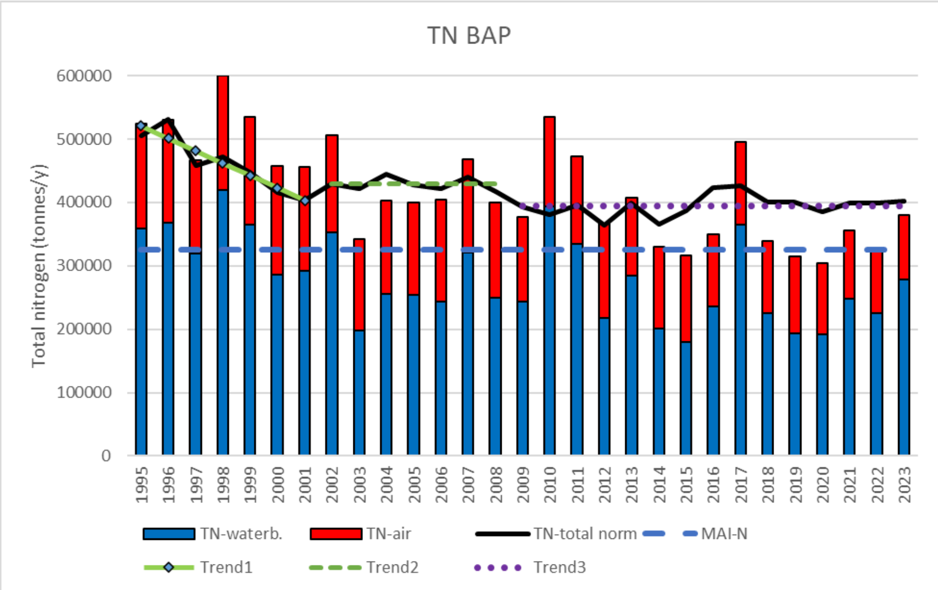
The trend analysis of the normalized **waterborne nitrogen inputs** showed a significant decrease since the reference period for only four sub-basins: Kattegat (22%), Baltic Proper and Danish Straits (19%) and Bothnian Sea (15%) (Results figures 2d, Results table 4 and Results table 5a). There was an increase in waterborne nitrogen inputs to Bothnian Bay (9.3%) and to Gulf of Riga (20%), with no trend to the Baltic Sea and Gulf of Finland. One breakpoint is identified for Baltic Sea and five sub-basins, and two breakpoints for Baltic Proper and Gulf of Finland. Only three sub-basins had significant recent reductions: Bothnian Sea (22%, breakpoint 2003), Bothnian Bay (10%, breakpoint 2008) and Kattegat (4.6%, breakpoint 2011). Two sub-basins had significant increases: Gulf of Riga (33%, breakpoint 2012) and Baltic Proper (21%, breakpoint 2009) corresponding to an annual increase of 3.0% and 1.5%, respectively (Results Table 6b). Waterborne nitrogen inputs increased with 33% to Gulf of Finland from 1995 to 2004 and decreased by 29% between 2004 and 2017, and from 2017 there was no trend but inputs where 18% higher than in 2016. For Baltic Proper there was a decrease with 18% from 1995 to 2002, no trend between 2002 and 2009, and since then inputs increased with 21%. For Bothnian Sea waterborne nitrogen inputs increased with 9% from 1995 to 2003 and for to the Baltic Sea they decreased with 16% from 1995 to 2016, and since then no trend is seen.

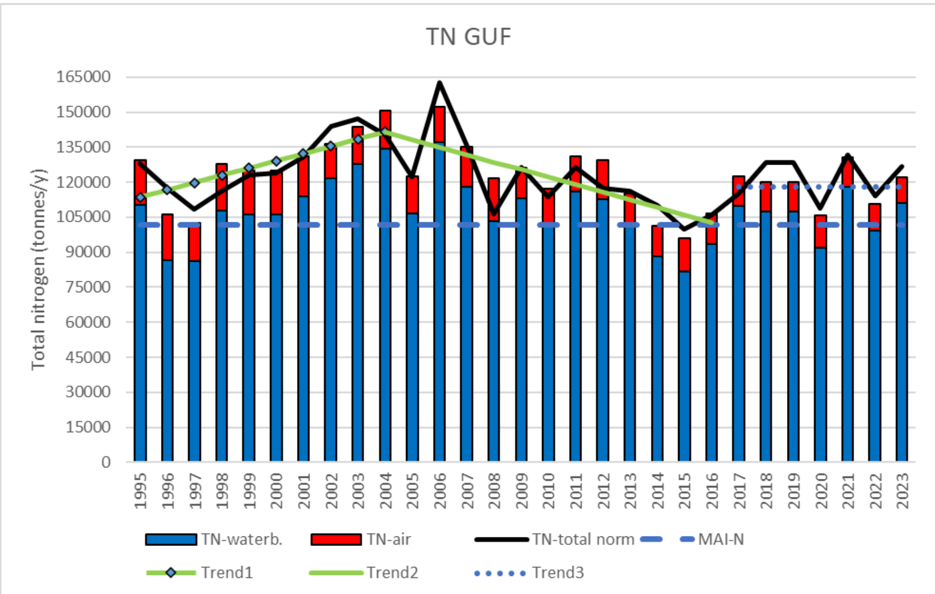
Trend analysis of the normalized **waterborne phosphorus inputs** showed a significant decrease since the reference period to the Baltic Sea and the seven sub-basins (Results figures 2e, Results table 4 and Results table 5b and d). The highest reductions were to Gulf of Finland (49%) and Gulf of Riga (34%), and the lowest reductions were found to Kattegat (21%) and Bothnian Bay (18%). The reduction to the Baltic Sea was 35%. A breakpoint in the timeseries was identified for four sub-basins: Danish Straits (2000), Bothnian Bay (2002), Gulf of Finland (2012) and Baltic Proper (2013). Danish Straits (18% or 0.8 % per year) and Bothnian Bay (12% or 0.6% per year) had significant reduction since their last breakpoint. For Gulf of Finland, there is an abrupt breakpoint, resulting in markedly lower waterborne phosphorus inputs after the breakpoint (50%). Abrupt jumps are often related to markedly improved wastewater treatment as occurred to Gulf of Finland around 2012, which is seen in Result Figure 3e as a marked reduction in direct point source inputs. Waterborne phosphorus inputs to Bothnian Sea (0.8 % per year), Gulf of Riga (1.5% per year) and Kattegat (0.9% per year) have consistently significant decreasing trends since 1995 (no breakpoint in the time series) (Results table 5d).

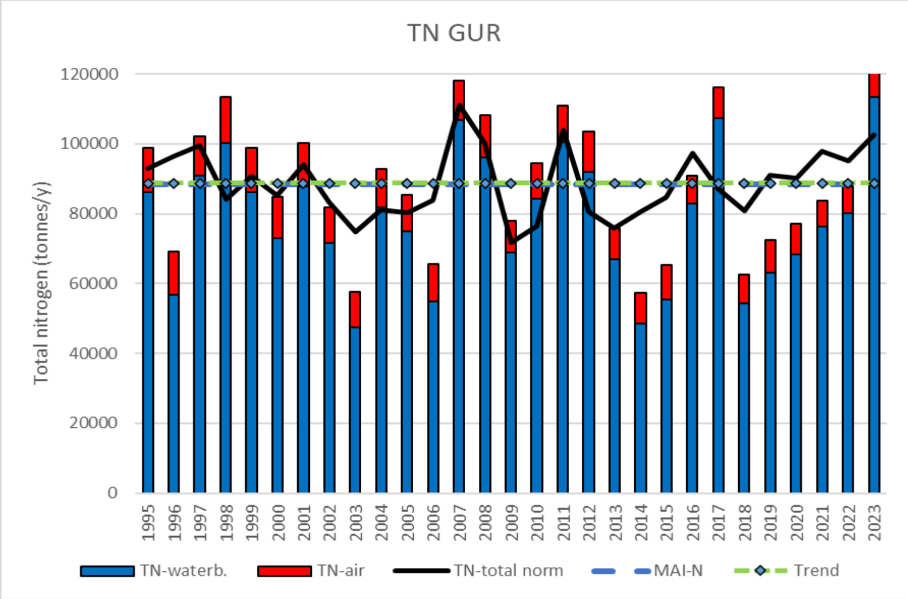

TN BAS
Total nitrogen (tonnes/y)
1250000
1125000
1000000
875000
750000
625000
500000
375000
250000
125000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2

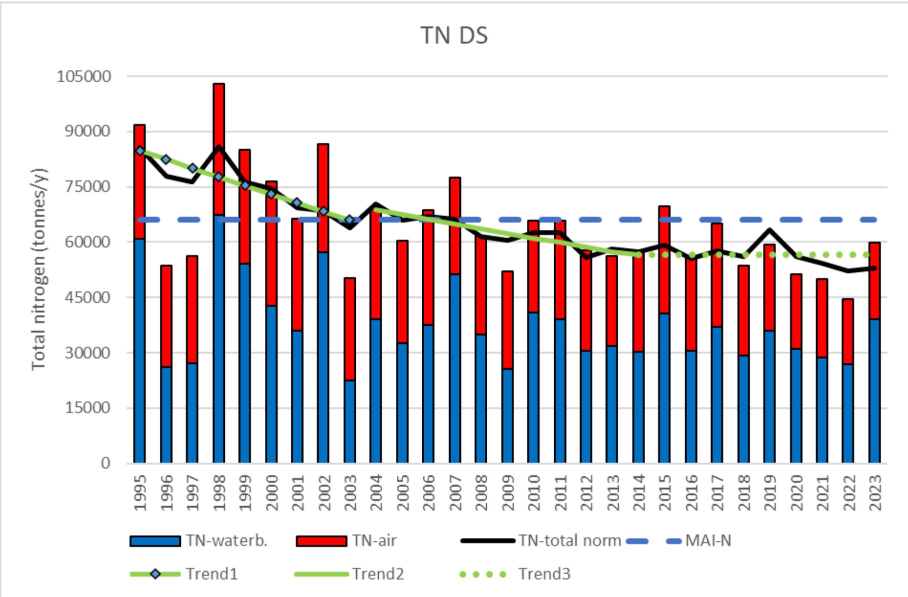

TN BOB
Total nitrogen (tonnes/y)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2

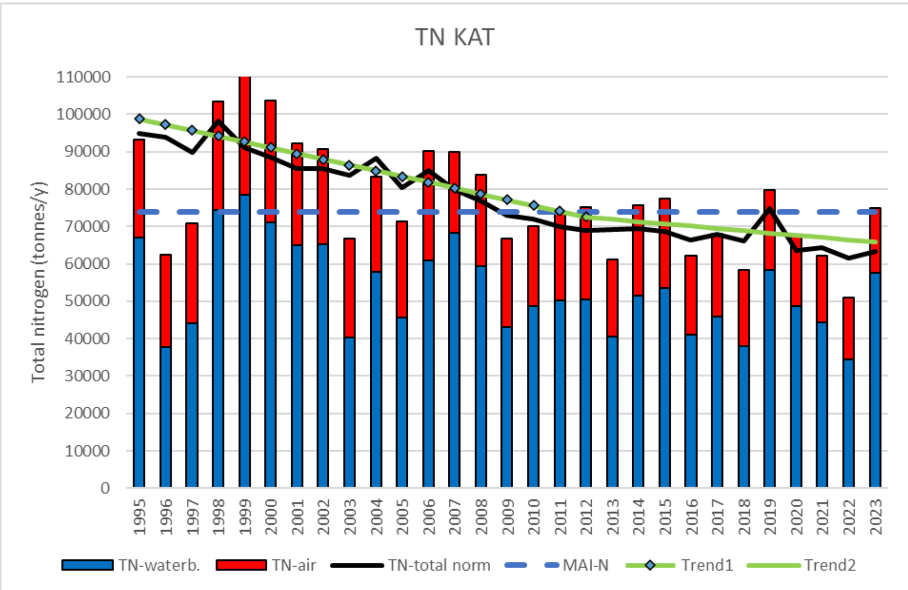

TN BOS
Total nitrogen (tonnes/y)
125000
100000
75000
50000
25000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2


TN BAP
Total nitrogen (tonnes/y)
600000
500000
400000
300000
200000
100000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2
Trend3

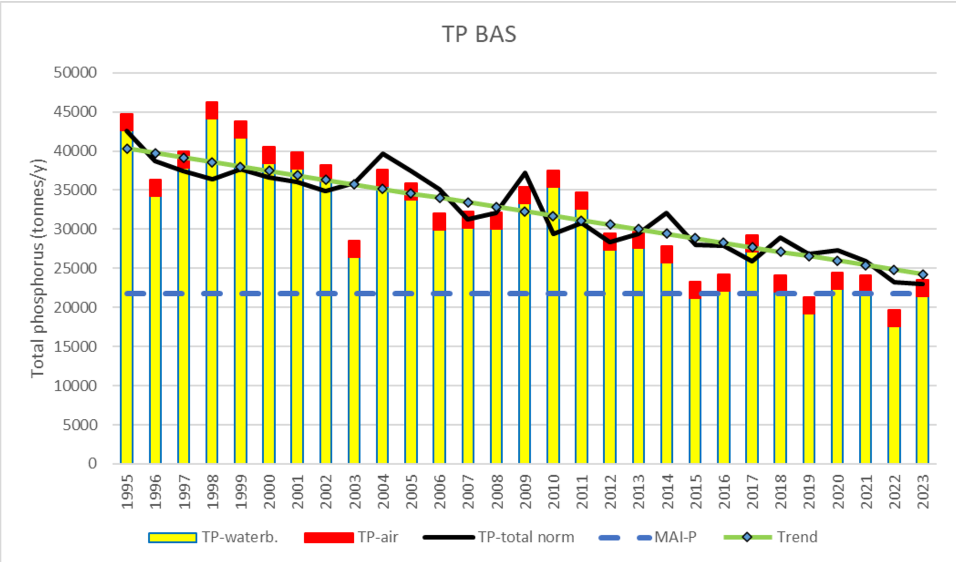

TN GUF
Total nitrogen (tonnes/y)
165000
150000
135000
120000
105000
90000
75000
60000
45000
30000
15000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2
Trend3

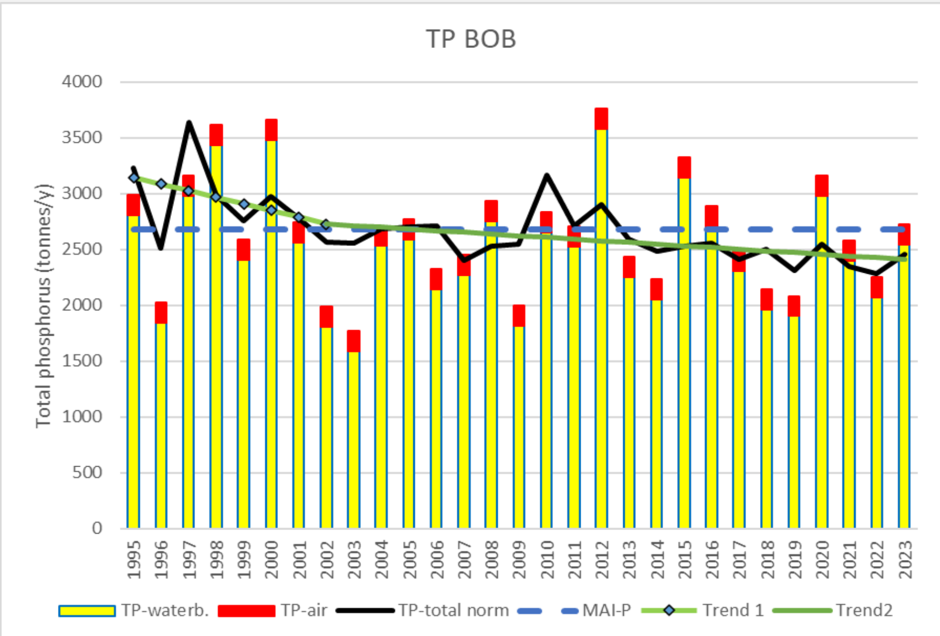

TN GUR
Total nitrogen (tonnes/y)
120000
100000
80000
60000
40000
20000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend

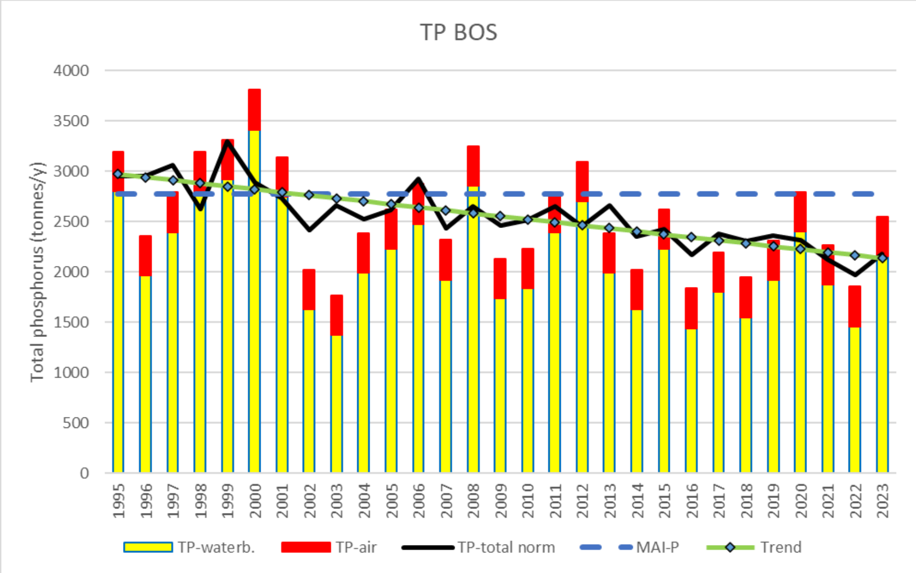

TN DS
Total nitrogen (tonnes/y)
105000
90000
75000
60000
45000
30000
15000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2
Trend3

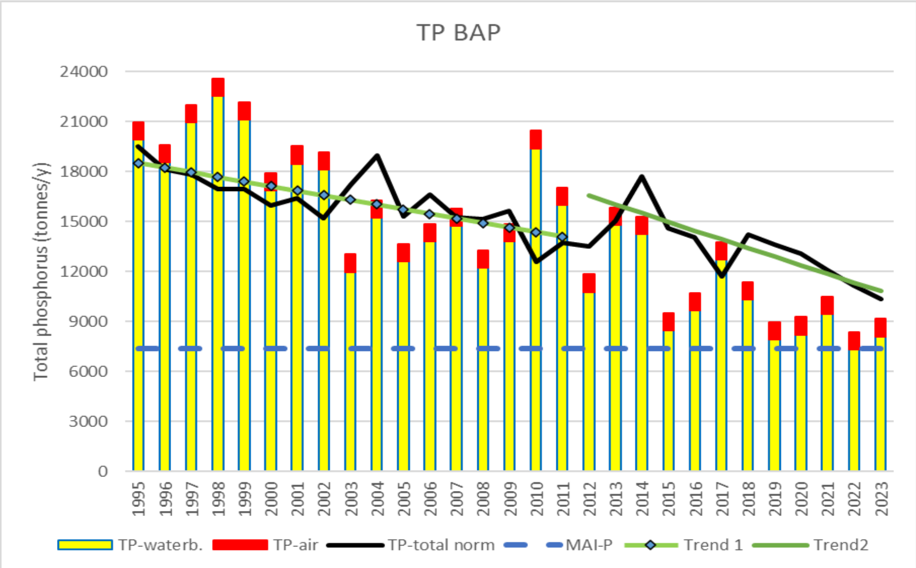

TN KAT
Total nitrogen (tonnes/y)
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-waterb.
TN-air
TN-total norm
MAI-N
Trend1
Trend2

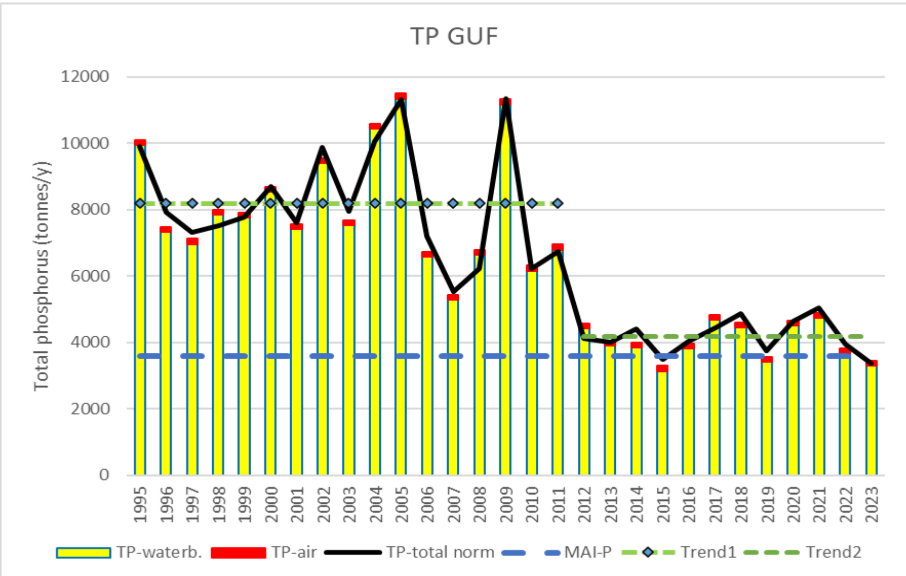
Results figure 2a. Actual total air- and waterborne annual input of nitrogen (TN) to the Baltic Sea and sub-basins from 1995 to 2023 (tonnes/y) (bars). The normalized total annual inputs of nitrogen are given as a black line. The trend line for normalized total nitrogen is given as a green line with markers. In cases when a breakpoint divides the trend into two parts, the second part (called trend 2) is shown by a green line without marker. In cases with two breaks points the third part (called trend 3) is indicated as a purple line. (Solid green trend line indicates a statistically significant trend while a dotted green line shows no statistically significant trend). The MAI as adopted by the 2013 HELCOM Copenhagen Ministerial Meeting (HELCOM 2013a) is shown as the bold dotted blue line.

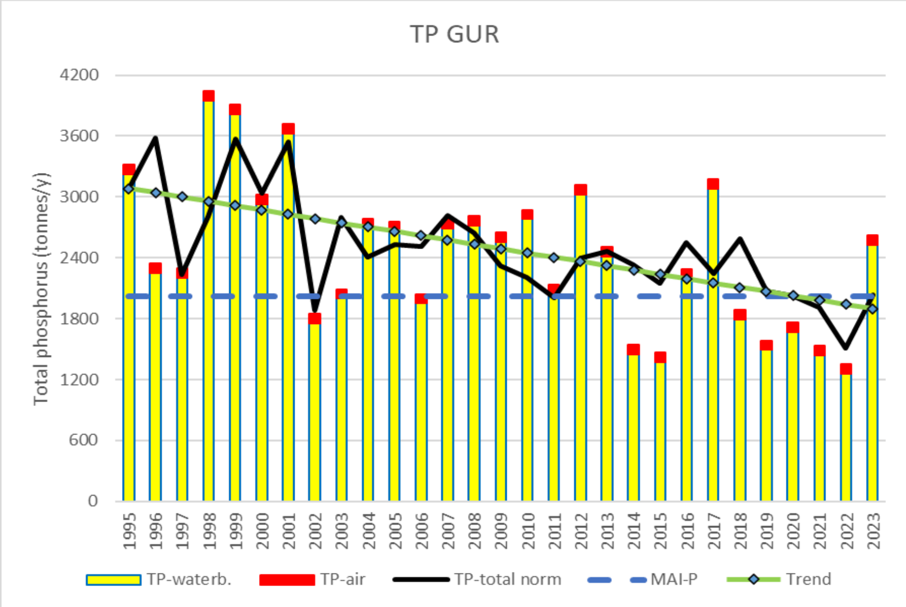


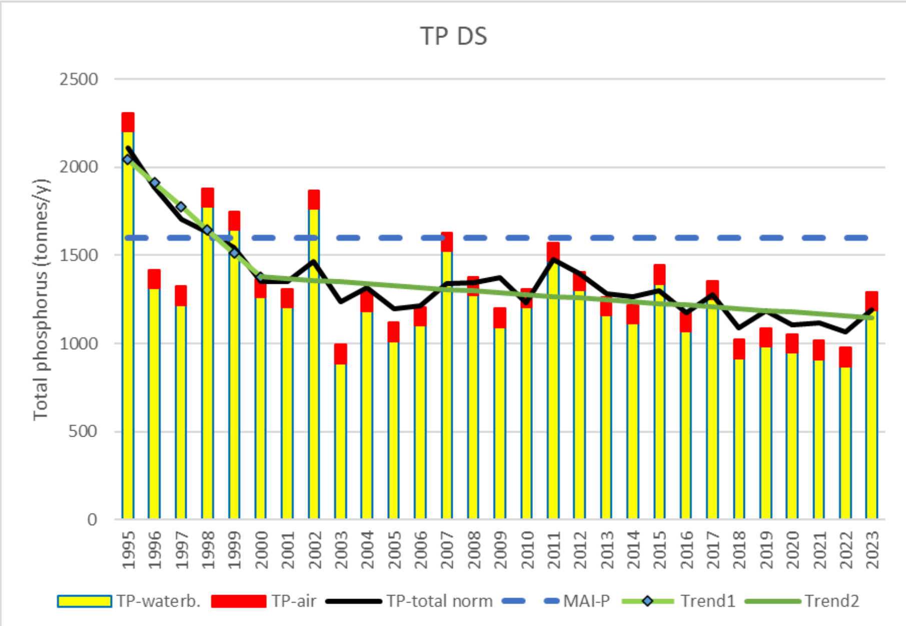


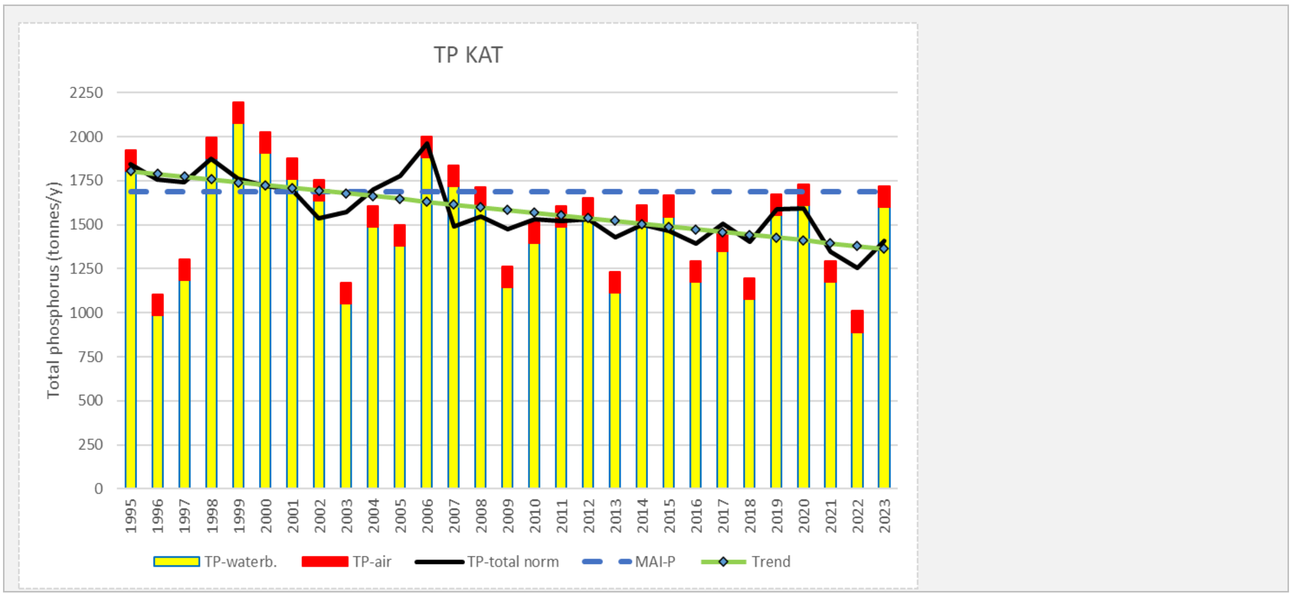

TP BOS
Total phosphorus (tonnes/y)
4000
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend


TP BAP
Total phosphorus (tonnes/y)
24000
21000
18000
15000
12000
9000
6000
3000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend 1
Trend2

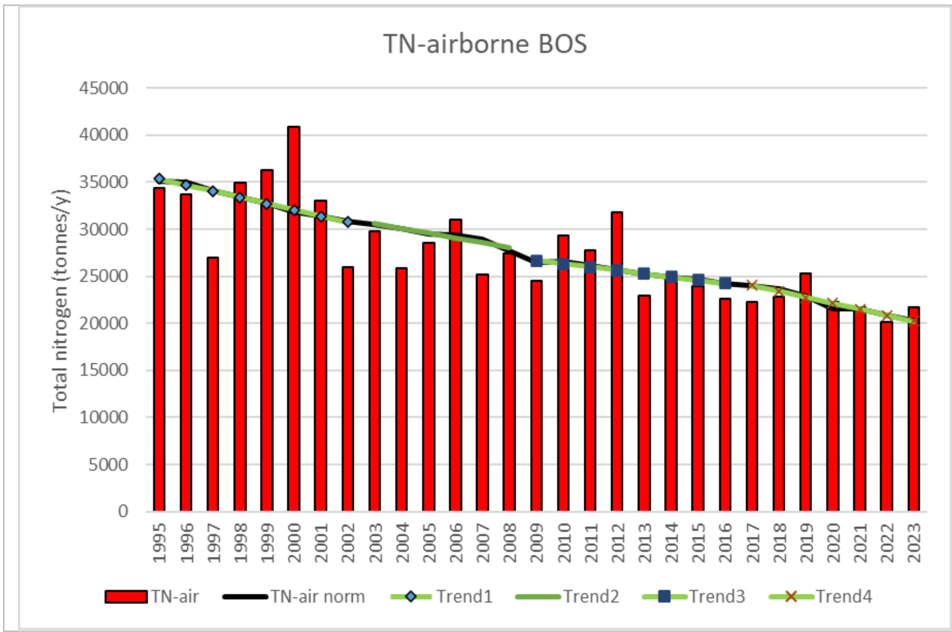

TP GUF
Total phosphorus (tonnes/y)
12000
10000
8000
6000
4000
2000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend1
Trend2

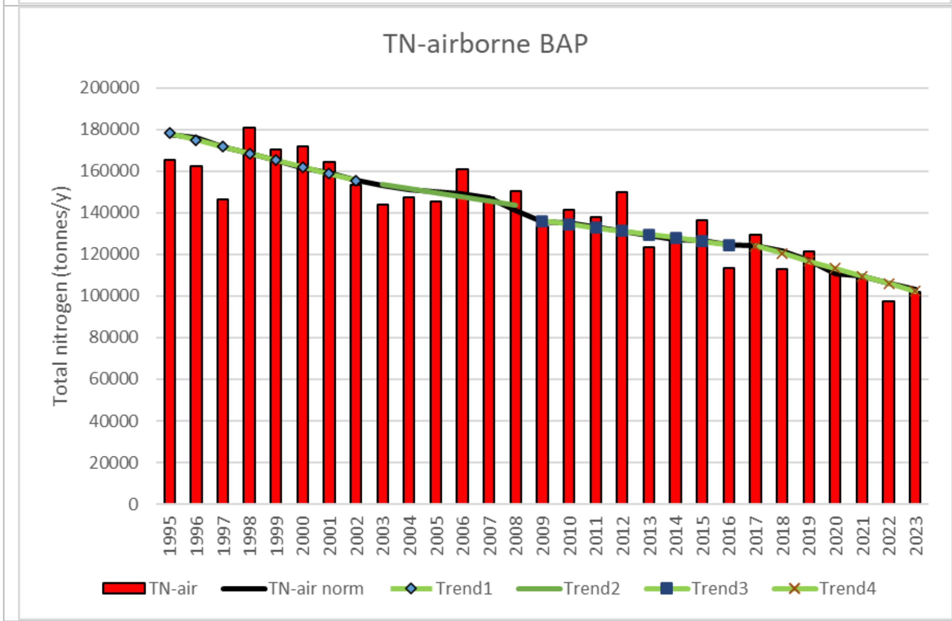

TP GUR
Total phosphorus (tonnes/y)
4200
3600
3000
2400
1800
1200
600
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend

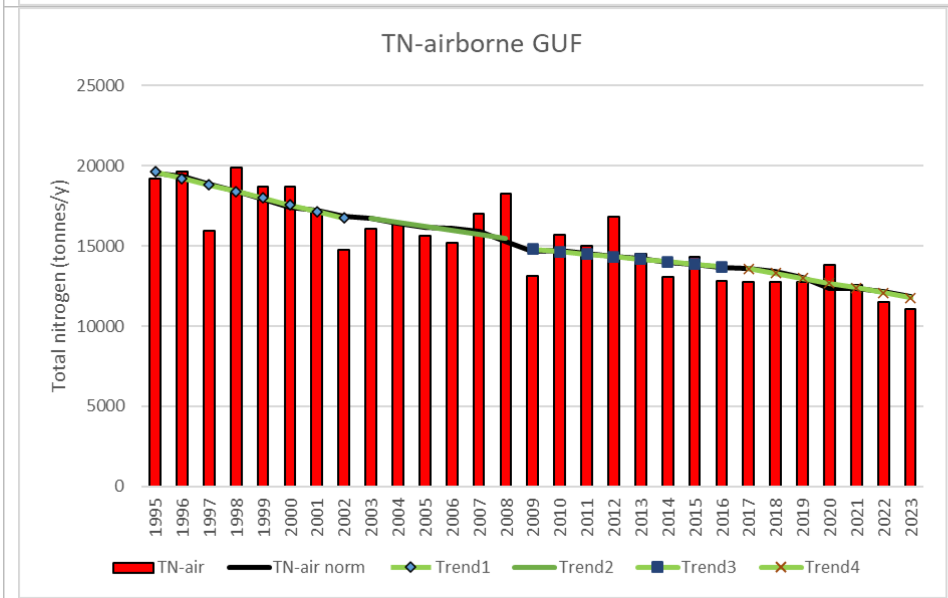

TP DS
Total phosphorus (tonnes/y)
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TP-waterb.
TP-air
TP-total norm
MAI-P
Trend1
Trend2

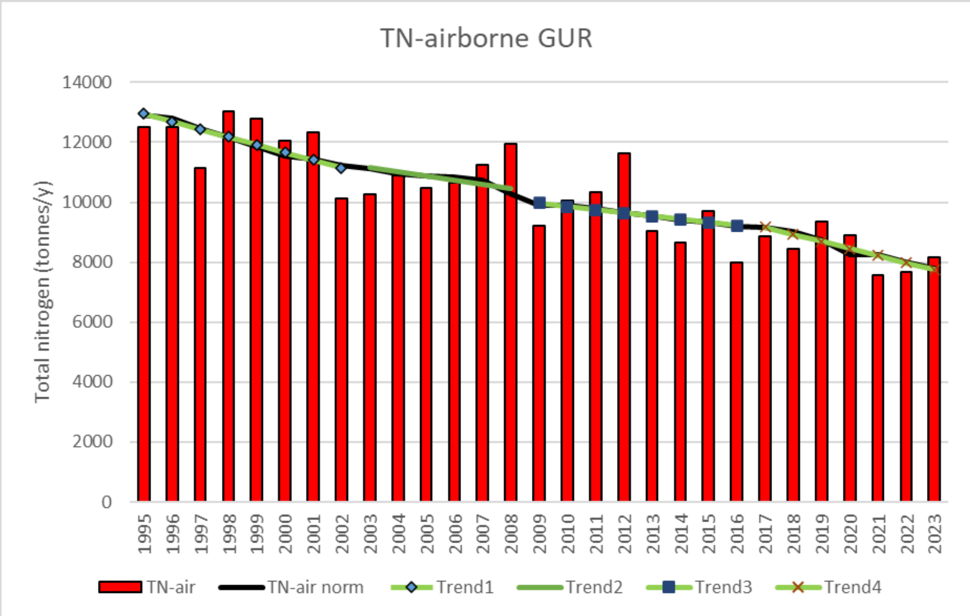


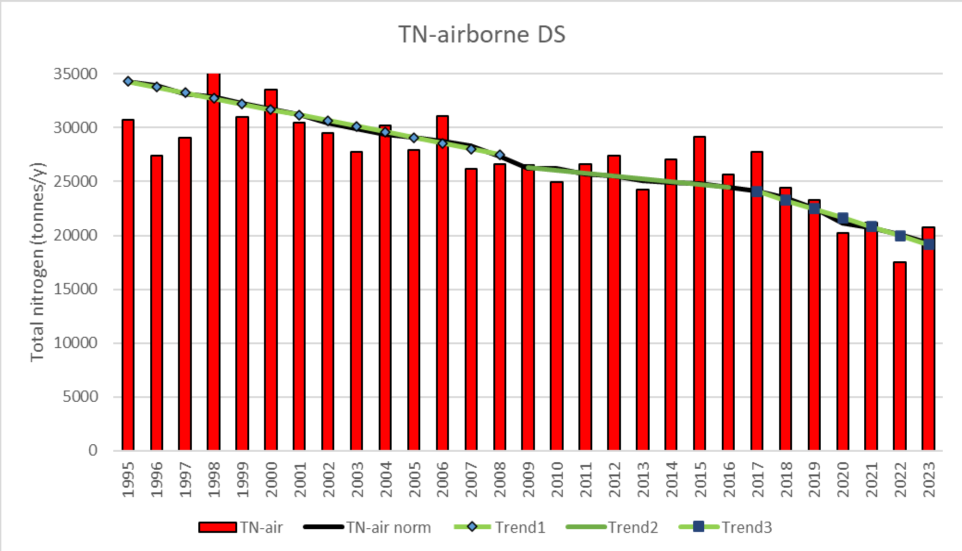
Results figure 2b. As figure Result 2a but for phosphorus (TP).

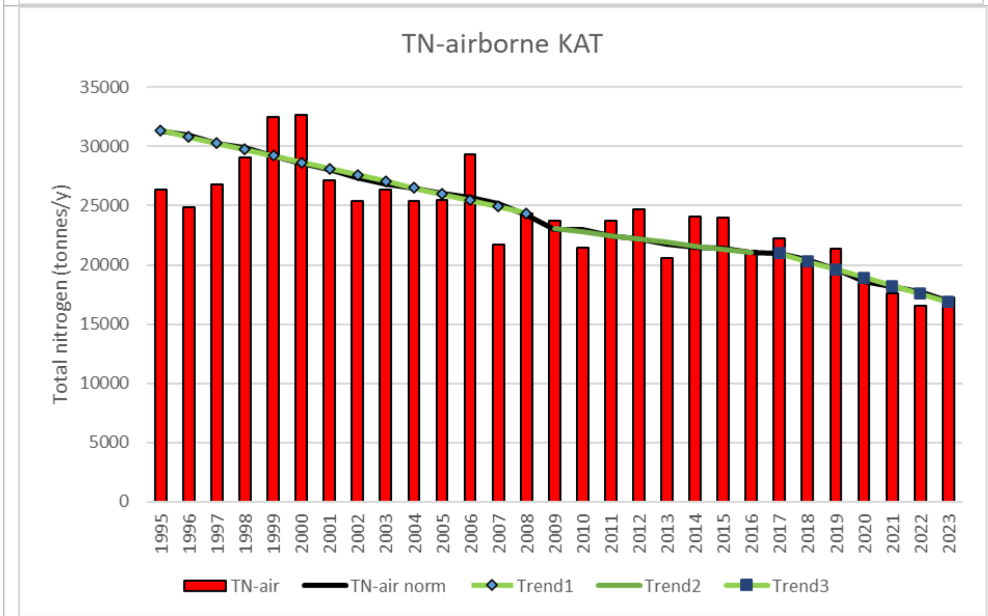

TN-airborne BOS
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Total nitrogen (tonnes/y)
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
TN-air
TN-air norm
Trend1
Trend2
Trend3
Trend4


TN-airborne BAP
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Total nitrogen (tonnes/y)
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
TN-air
TN-air norm
Trend1
Trend2
Trend3
Trend4

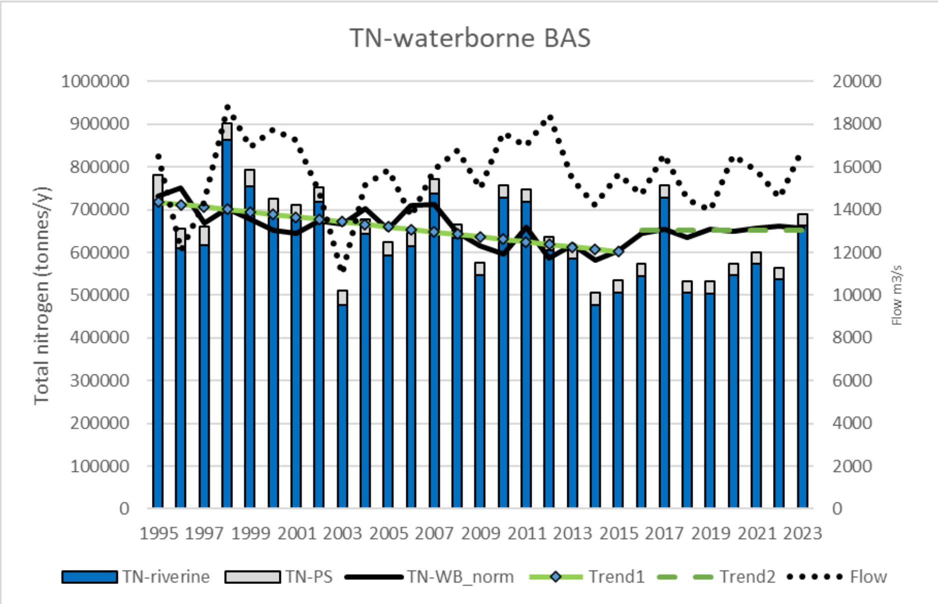

TN-airborne GUF
25000
20000
15000
10000
5000
0
Total nitrogen (tonnes/y)
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
TN-air
TN-air norm
Trend1
Trend2
Trend3
Trend4

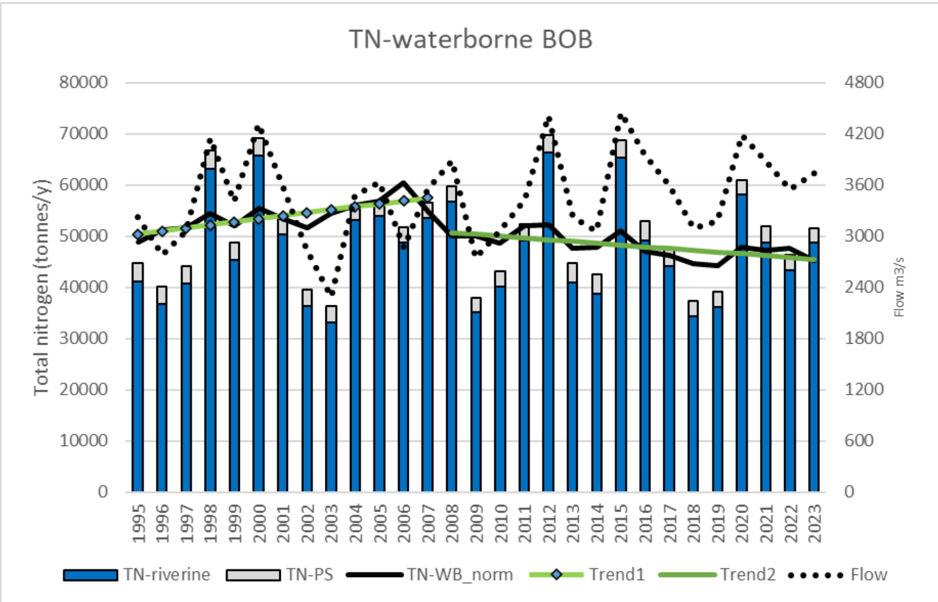

TN-airborne GUR
Total nitrogen (tonnes/y)
0
2000
4000
6000
8000
10000
12000
14000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-air
TN-air norm
Trend1
Trend2
Trend3
Trend4

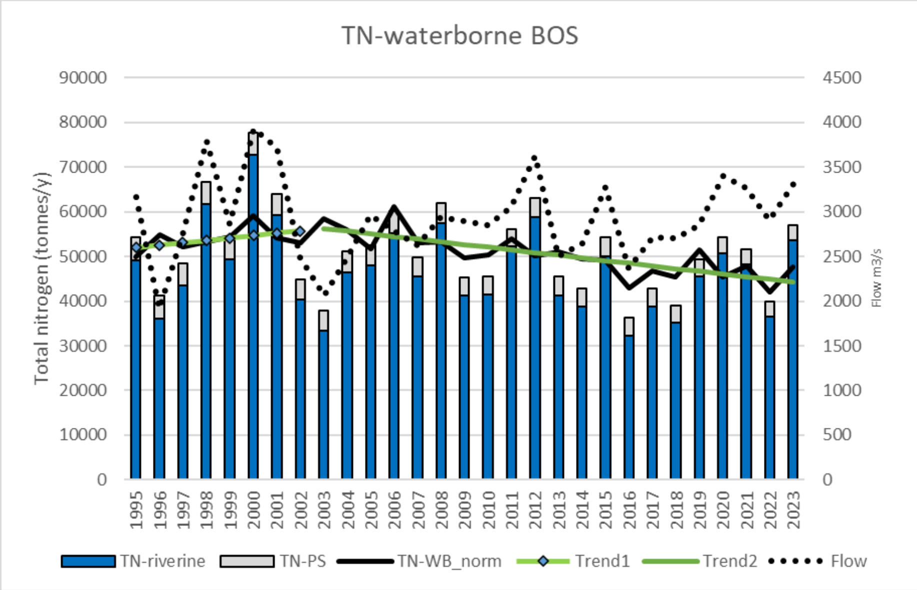

TN-airborne DS
Total nitrogen (tonnes/y)
0
5000
10000
15000
20000
25000
30000
35000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-air
TN-air norm
Trend1
Trend2
Trend3

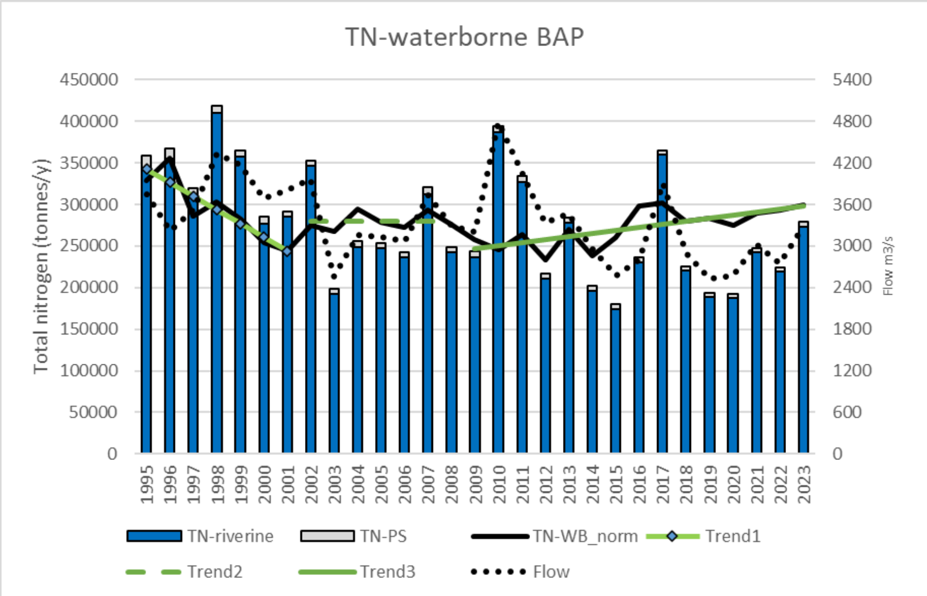

TN-airborne KAT
Total nitrogen (tonnes/y)
0
5000
10000
15000
20000
25000
30000
35000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-air
TN-air norm
Trend1
Trend2
Trend3

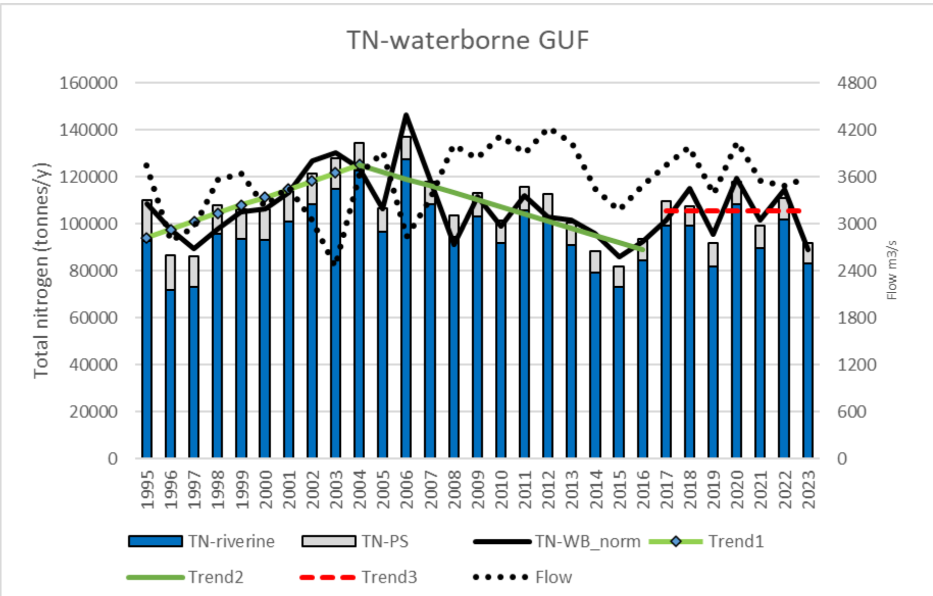
Results figure 2c. Actual annual airborne deposition of nitrogen (TN) to the Baltic Sea and sub-basins from 1995 to 2023 (tonnes/y). The normalized annual airborne deposition inputs of nitrogen are given as a black line. The trend line for normalized total nitrogen deposition is given as a green line with markers. In cases when a breakpoint divides the trend into two parts, the second part (called trend 2) is shown by a green line without marker. In case with two or three breakpoints divide the trend into three or four parts, respectively, the third and fourth part is shown as a green line with (different) markers. Solid trend line shows statistically significant trend and dotted line no statistically significant trend.

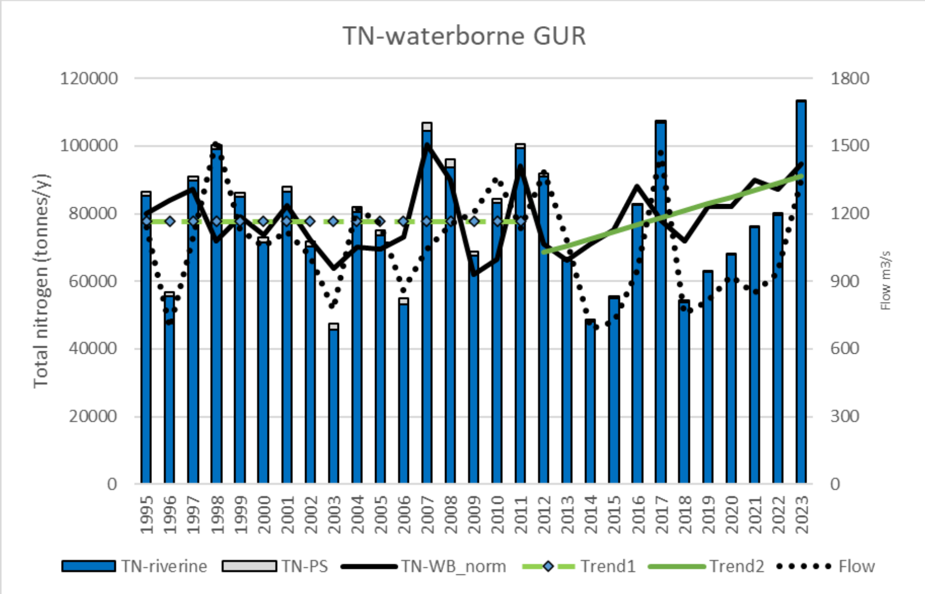


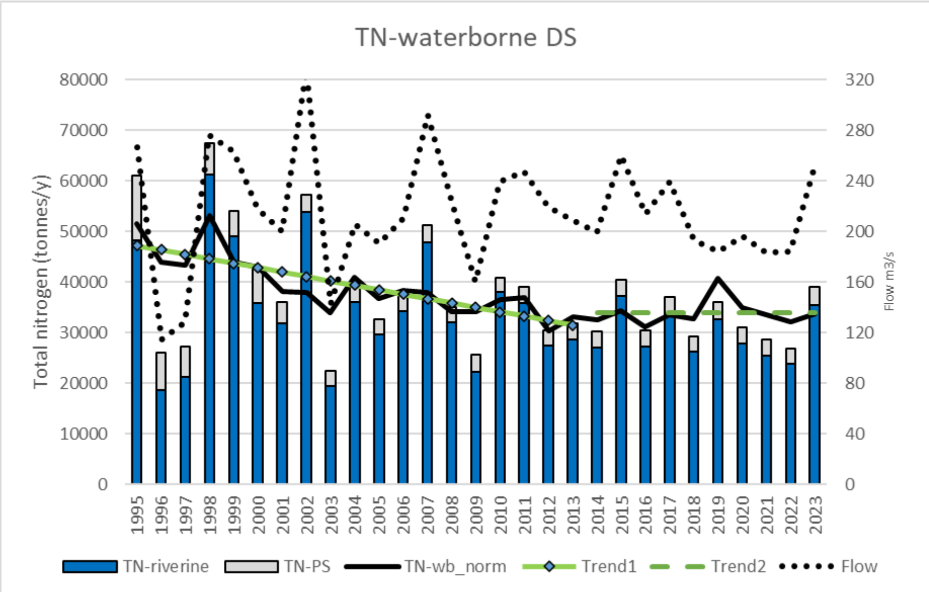


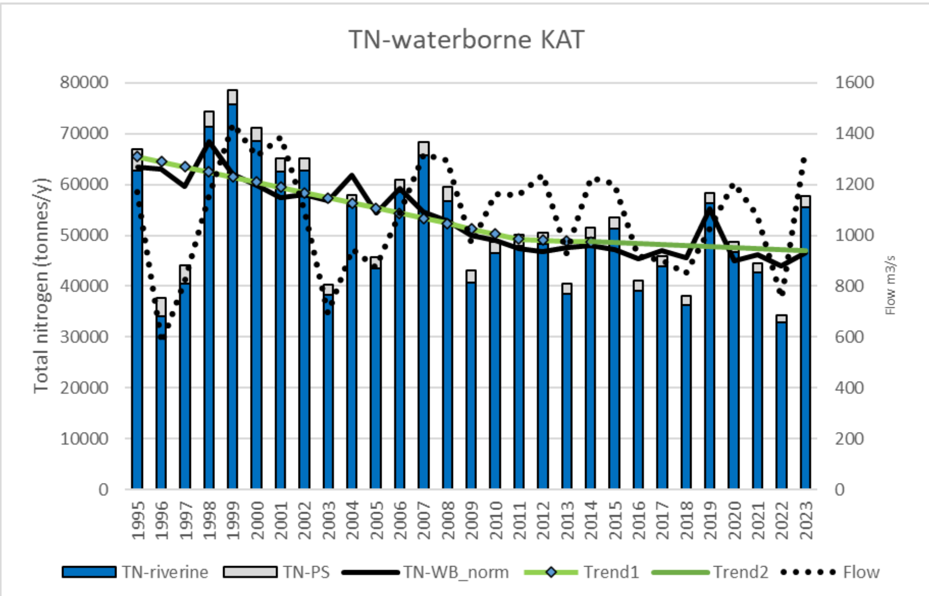

TN-waterborne BOS
Total nitrogen (tonnes/y)
Flow m3/s
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Flow


TN-waterborne BAP
Total nitrogen (tonnes/y)
Flow m3/s
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Trend3
Flow

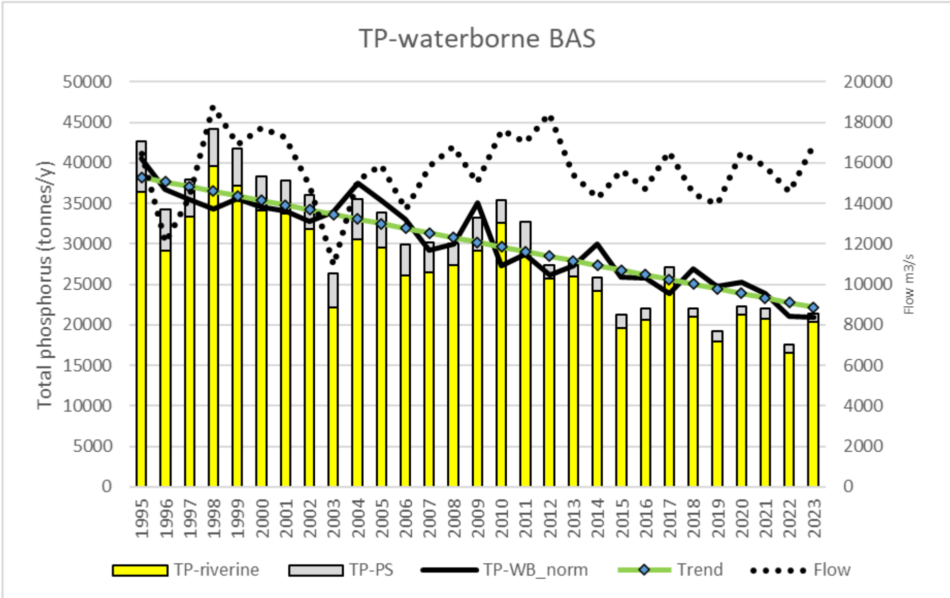

TN-waterborne GUF
Total nitrogen (tonnes/y)
Flow m3/s
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Trend3
Flow

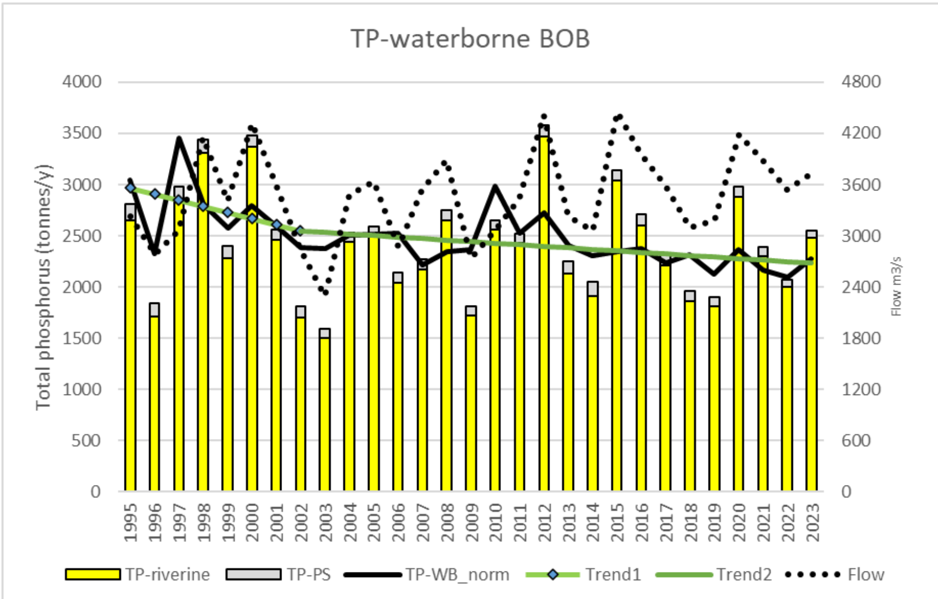

TN-waterborne GUR
Total nitrogen (tonnes/y)
Flow m3/s
0
20000
40000
60000
80000
100000
120000
0
300
600
900
1200
1500
1800
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Flow

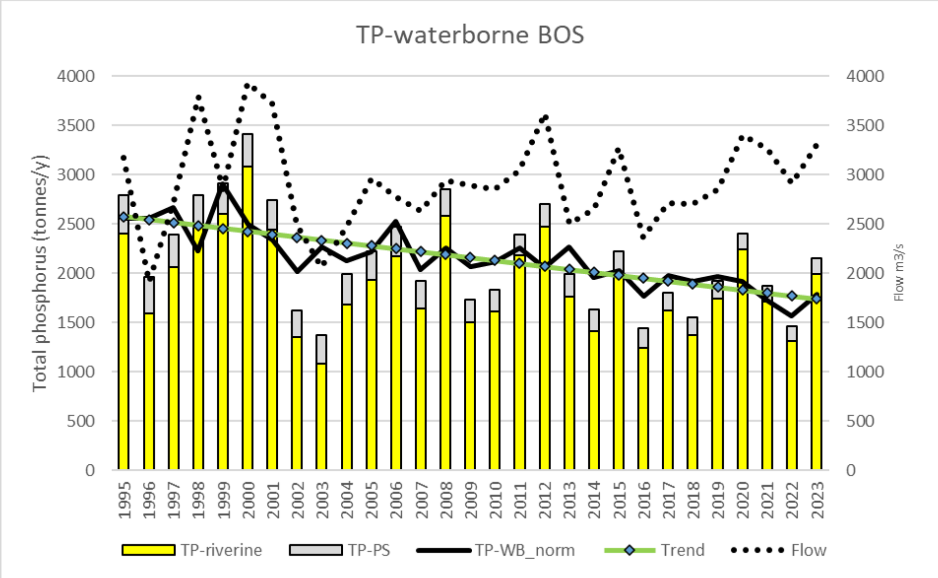

TN-waterborne DS
Total nitrogen (tonnes/y)
Flow m3/s
0
10000
20000
30000
40000
50000
60000
70000
80000
0
40
80
120
160
200
240
280
320
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-riverine
TN-PS
TN-wb_norm
Trend1
Trend2
Flow

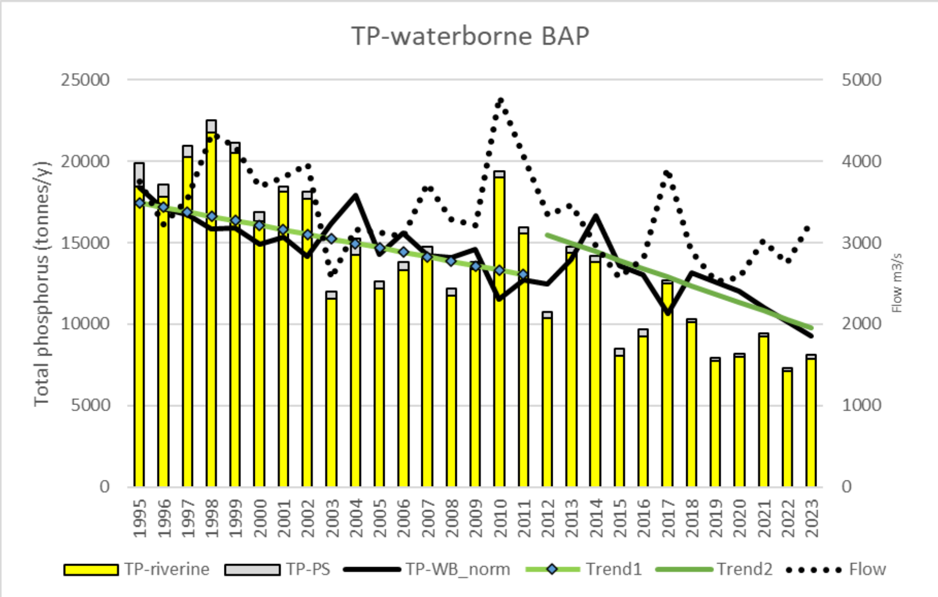

TN-waterborne KAT
Total nitrogen (tonnes/y)
Flow m3/s
0
10000
20000
30000
40000
50000
60000
70000
80000
0
200
400
600
800
1000
1200
1400
1600
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
TN-riverine
TN-PS
TN-WB_norm
Trend1
Trend2
Flow

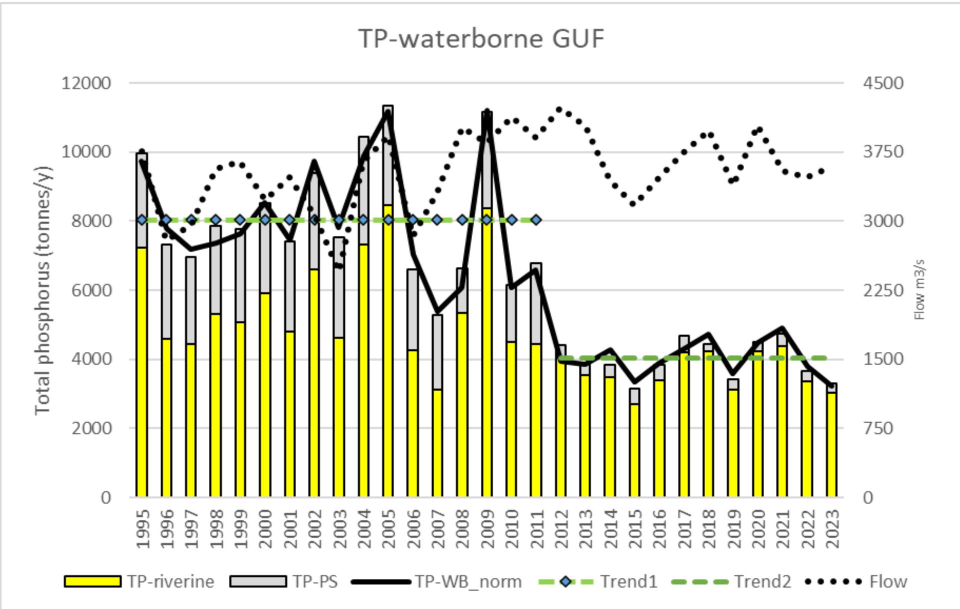
Results figure 2d. Actual annual riverine and direct point source inputs (the sum is the waterborne inputs) of nitrogen (TN) (tonnes/y, left y-axis) and total waterborne flow (m³/s, dotted black line, right y-axis) to the Baltic Sea and sub-basins from 1995 to 2023. The normalized annual waterborne inputs of nitrogen are given as a black line. The trend line for normalized total nitrogen waterborne input is given as a green line with markers. In cases when a breakpoint divides the trend into two parts, the second part (called trend 2) is shown by a green line without marker. In cases with two breaks points the third part (called trend 3) is indicated as a red line without marker. Solid trend line shows statistically significant trend and dotted line no statistically significant trend.

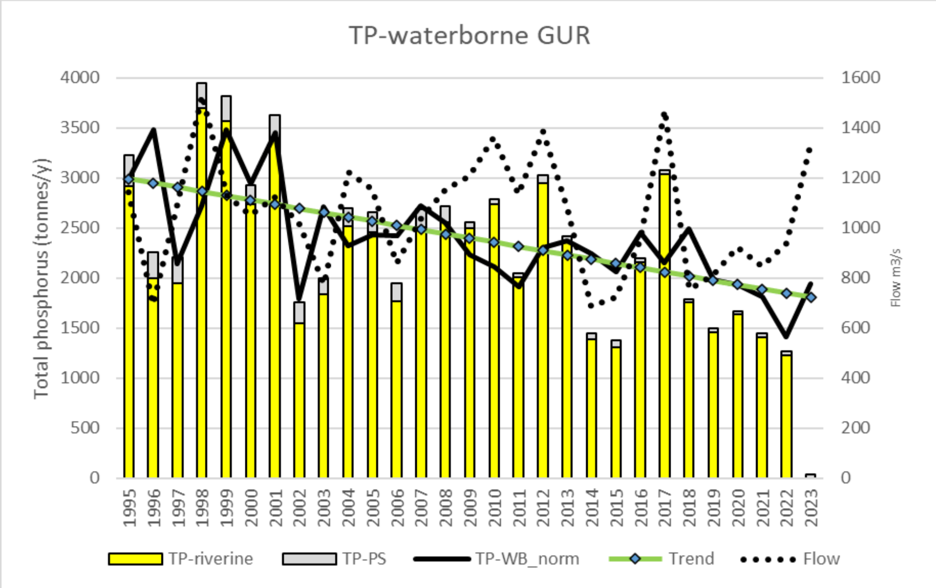


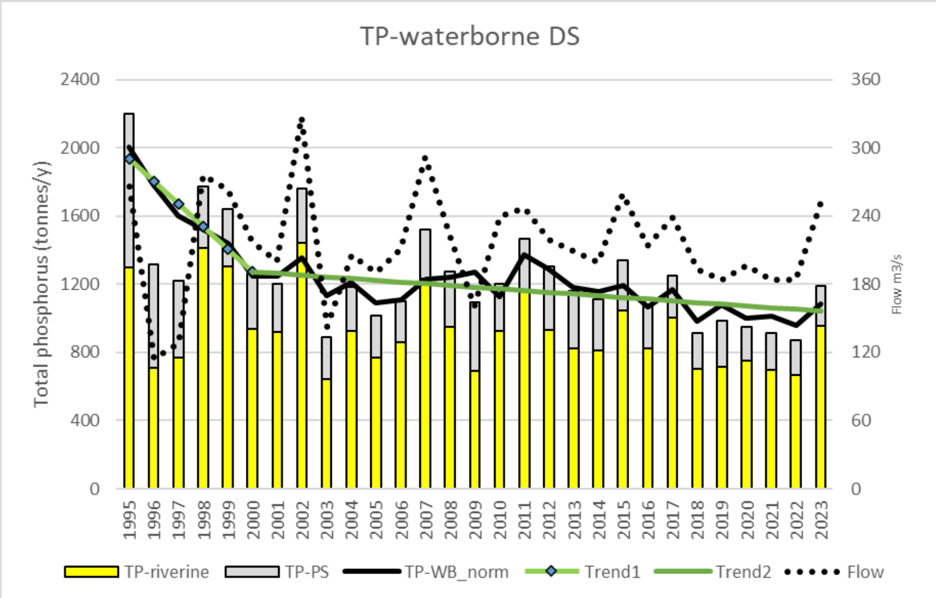


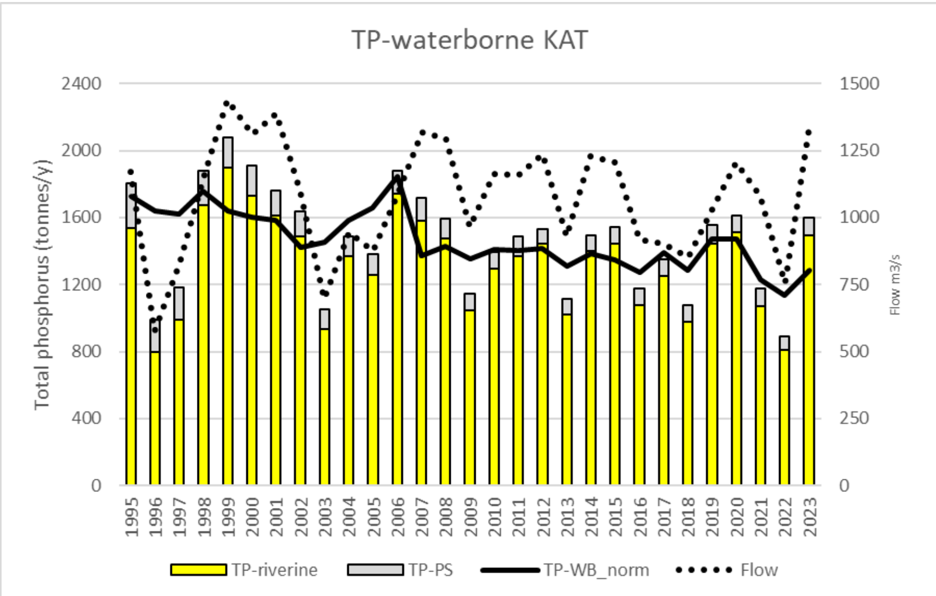

TP-waterborne BOS
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend
Flow


TP-waterborne BAP
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend1
Trend2
Flow


TP-waterborne GUF
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend1
Trend2
Flow


TP-waterborne GUR
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend
Flow


TP-waterborne DS
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Trend1
Trend2
Flow


TP-waterborne KAT
Total phosphorus (tonnes/y)
Flow m3/s
TP-riverine
TP-PS
TP-WB_norm
Flow

Results figure 2e. As figure Result 2d but for phosphorus (TP).

Results tables 5a-d include an overview of the identified breakpoints in the 1995-2023 time series of airborne nitrogen deposition, waterborne, and for total nitrogen and phosphorus inputs to Baltic Sea and its sub-basins, respectively. The tables include statistically significant changes since the reference period (1997-2003) and since the last breakpoint (if any breakpoint is identified) as change in % (Results table 5a and 5c) and as change in % per year during the period (Result tables 5b and 5d). Change after the last breakpoint is an indication of recent changes. As atmospheric deposition of phosphorus was set as an annual fixed rate of 5 kg per km^{-2} the waterborne inputs determine changes in total phosphorus inputs to the Baltic Sea. Main results of the tables are described in the paragraphs before the result figures 2a-e.

Result table 5a. Years with statistically identified breakpoints in trend lines of airborne, waterborne and total nitrogen inputs to the Baltic Sea and its sub-basins during 1995-2023. Changes in in these inputs since the reference period (1997-2003) and the last breakpoint (if any) is given in percentages. "-" = no significant trend. n.r. = not relevant as there is no breakpoint

	TN-airborne			**TN waterborne**			**Total TN input**		
	Breakpoints	**Change (%) since reference period**	**Change (%) after last breakpoint**	**Breakpoints**	**Change (%) since reference period**	**Change (%) after last breakpoint**	**Breakpoints**	**Change (%) since reference period**	**Change (%) after last breakpoint**
Bothnian Bay	2003, 2009, 2017	-38	-16	2008	-15	-10	2008	-18	-12
Bothnian Sea	2003, 2009, 2017	-38	-16	2003	-19	-21	2003	-26	-19
Baltic Proper	2003, 2009, 2017	-37	-17	2002, 2009	9,3	21	2002, 2009	-9.3	-
Gulf of Finland	2003, 2009, 2017	-33	-13	2004, 2017	-	-	2004, 2017	-	-
Gulf of Riga	2003, 2009, 2017	-33	-16	2012	20	33		-	n.r
Danish Straits	2009, 2017	-39	-21	2014	-19	-	2004, 2014	-23	-
Kattegat	2009, 2017	-41	-20	2011	-22	-4.6	2012	-26	-15
Baltic Sea	2003, 2009, 2017	-37	-17	2016	-	-	2016	-11	-
ARC	2003, 2009, 2017	-37	-16	2002	-20	-22	2003	-29	-22
BOP	2003, 2009, 2017	-37	-16	2003	-19	-21	2003	-25	-18

Results table 5b. As tables 5a but significant changes are expressed as % change per year during the period.

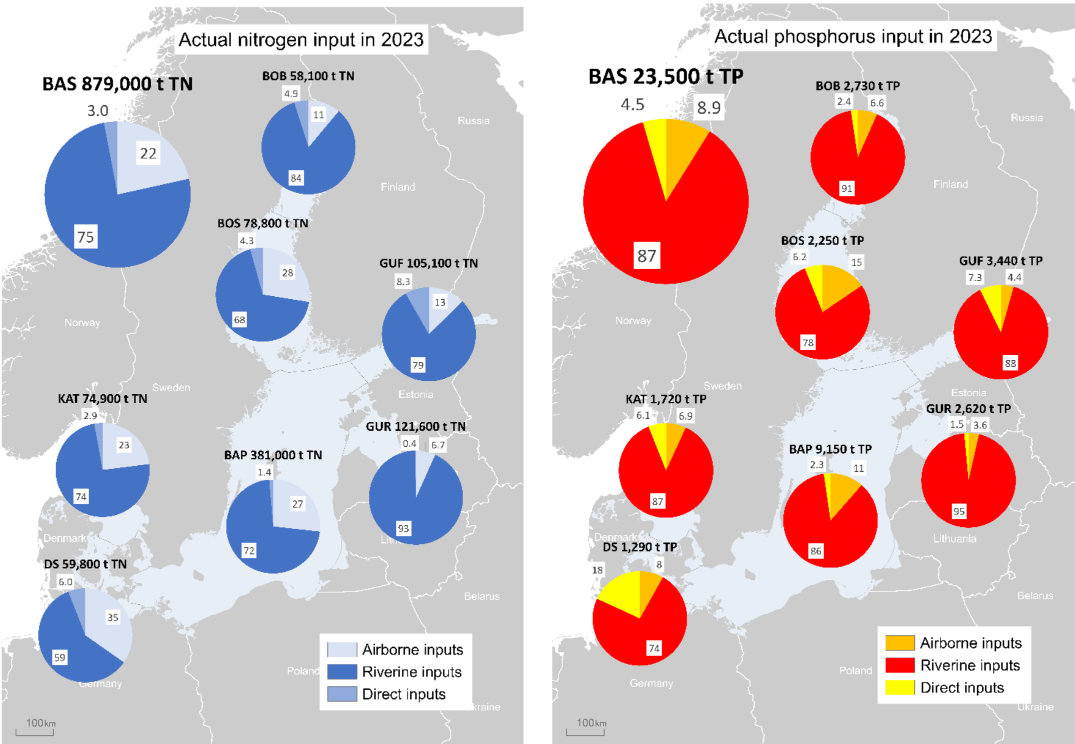
	TN-airborne			TN waterborne			Total TN input		
	Breakpoints	Change (%/y) since reference period	Change (%/y) after last breakpoint	Breakpoints	Change (%/y) since reference period	Change (%/y) after last breakpoint	Breakpoints	Change (%/y) since reference period	Change (%/y) after last breakpoint
Bothnian Bay	2003, 2009, 2017	-1.6	-2.7	2008	-0,6	-0.7	2008	-0.8	-0.8
Bothnian Sea	2003, 2009, 2017	-1.6	-2.7	2003	-0.8	-1.1	2003	-1.1	-1.0
Baltic Proper	2003, 2009, 2017	-1.6	-2.9	2002, 2009	0.4	1.5	2002, 2009	-0.4	-
Gulf of Finland	2003, 2009, 2017	-1.4	-2.2	2004, 2017	-	-	2004, 2017	-	-
Gulf of Riga	2003, 2009, 2017	-1.4	-2.6	2012	0.9	3.0		-	-
Danish Straits	2009, 2017	-1.7	-3.4	2014	-0.8	-	2004, 2014	-1.0	-
Kattegat	2009, 2017	-1.8	-3.3	2011	-1.0	-0.4	2012	-1.1	-1.3
Baltic Sea	2003, 2009, 2017	-1.6	-2.9	2016	-	-	2016	-0.5	-
ARC	2003, 2009, 2017	-1.6	-2.7	2002	-0.8	-1.0	2003	-1.3	-1.1
BOP	2003, 2009, 2017	-1.6	-2.6	2003	-0.8	-1.0	2003	-1.1	-0.9

Results table 5c. Years with statistically identified breakpoints in trend lines of waterborne and total phosphorus inputs to the Baltic Sea and its sub-basins during 1995-2023. Changes in in these inputs since the reference period (1997-2003) and the last breakpoint (if any) is given in percentages. “-“ = no significant trend. n.r. =not relevant as there is no breakpoint.

	TP waterborne			Total TP input		
	Breakpoints	**Change (%) since reference period**	**Change (%) after last breakpoint**	**Breakpoints**	**Change (%) since reference period**	**Change (%) after last breakpoint**
Bothnian Bay	2002	-18	-12	2002	-17	-12
Bothnian Sea		-28	n.r.		-24	n.r.
Baltic Proper	2013	-37	-35	2013	-35	-32
Gulf of Finland	2012	-49	-	2012	-48	-
Gulf of Riga		-34	n.r.		-33	n.r.
Danish Straits	2000	-24	-18	2000	-22	-17
Kattegat		-21	n.r.		-20	n.r.
Baltic Sea		-35	n.r.		-33	n.r.
ARC	2006	-28	-35	2006	-25	-31
BOP	2001	-28	-23	2001	-24	-19

Results table 5d As tables 5c but significant changes are expressed as % change per year during the period.

	TP waterborne			Total TP input		
	Breakpoints	**Change (%) since reference period**	**Change (%) after last breakpoint**	**Breakpoints**	**Change (%/y) before first**	**Change (%/y) after last**
Bothnian Bay	2002	-0.8	-0.6	2002	-0.7	-0.6
Bothnian Sea		-1.2	n.r.		-1.0	-1.0
Baltic Proper	2013	-1.6	-3.5	2013	-1.5	-3.2
Gulf of Finland	2012	-2.1	-	2012	-2.1	-
Gulf of Riga		-1.5	n.r.		-1.4	-1.4
Danish Straits	2000	-1.0	-0.8	2000	-1.0	-0.7
Kattegat		-0.9	n.r.		-0.9	-0.9
Baltic Sea		-1.5	n.r.		-1.5	-1.4
ARC	2006	-1.2	-2.0	2006	-1.1	-1.8



Results figure 3. The actual inputs of riverine, direct (point sources discharging directly into the sea) and airborne nitrogen (left) and phosphorus (right) to the Baltic Sea in 2023.

Comparing MAI assessments 2015-2023

The classification of achieved reductions in the MAI assessment 2015-2023 are very consistent for both nitrogen and phosphorus (Results tables 6a and 6b).

Maximum allowable nitrogen inputs were fulfilled in three sub-basins (Bothnian Sea, Danish Straits and Kattegat) in the nine consecutive annual assessments (2015-2023). MAI was not fulfilled for Baltic Proper, Gulf of Finland and for the Baltic Sea in any assessment. MAI was not fulfilled in the Gulf of Riga in 2016-2019 and 2023. For Bothnian Bay (2015-2017) and Gulf of Riga (2015, 2020-2022), MAI fulfilment could not be judged due to statistical uncertainty on inputs. MAI has been fulfilled for Bothnian Bay since 2018. Bothnian Bay has improved its classification since 2015. Remaining reduction (expressed in percentages of MAI) have been reduced for Baltic Proper and Gulf of Riga since 2017. Remaining reduction has increased to Gulf of Finland.

Maximum allowable phosphorus inputs were only fulfilled in Kattegat for the nine consecutive annual assessments (2015-2023). For Bothnian Sea and Danish Straits MAI has been fulfilled since 2016, but in 2015 fulfilment could not be judged due to statistical uncertainty on total phosphorus inputs. MAI was not fulfilled in Baltic Proper and for the Baltic Sea in any of the nine MAI assessments. MAI was not fulfilled in Gulf of Finland in 2015, 2017, 2019-2023. MAI was not fulfilled in Gulf of Riga 2015-2020 but during 2021-2023 fulfilment could not be judged due to statistical uncertainty on inputs. For Bothnian Bay (2015-2017) and Gulf of Finland (2016 and 2018) MAI fulfilment could not be judged due to statistical uncertainty on inputs. High uncertainty on the inputs to Gulf of Finland is one reason for the changing status of fulfilment of MAI. In 2018 -2023 MAI was fulfilled for Bothnian Bay, Bothnian Bay, Bothnian Sea and Danish Straits. Remaining reduction to fulfill MAI has decreased for all sub-basins not fulfilling MAI including Gulf of Riga where fulfilment cannot be judged due to uncertainty on phosphorus inputs.

Result table 6a. Classification of achieving MAI in 2015 (1995-2015 data), 2016 (1995-2016 data), 2017 (1995-2017 data), 2018 (1995-2018 data), 2019 (1995-2019), 2020 (1995-2020), 2021 (1995-2021), 2022 (1995-2022) and 2023 (1995-2023) for nitrogen: green=MAI fulfilled, yellow= fulfilment is not determined due to statistical uncertainty, and red=MAI not fulfilled.
Number in cells indicates exceedance of MAI in percentages of MAI. They are not shown for 2015-2016 due to changed methodology from 2017 assessment.

	Classification of achieved reduction of TN								
Baltic Sea sub-basin	**TN2015**	**TN2016**	**TN2017**	**TN2018**	**TN2019**	**TN2020**	**TN 2021**	**TN2022**	**TN 2023**
Bothnian Bay			1						
Bothnian Sea									
Baltic Proper			33	28	27	25	24	23	24
Gulf of Finland			12	14	13	16	26	26	23
Gulf of Riga			7	5	5	4	3	2	4
Danish Straits									
Kattegat									
Baltic Sea			13	11	11	10	11	11	11

Result table 6b. Classification of achieving MAI in 2015 (1995-2015 data), 2016 (1995-2016 data), 2017 (1995-

2017 data), 2018 (1995-2018 data), 2019 (1995-2019), 2020 (1995-2020), 2021 (1995-20219, 2022 (1995-2022) and 2023 (1995-2023) for phosphorus: green=MAI fulfilled, yellow= fulfilment is not determined due to statistical uncertainty, and red=MAI not fulfilled
Number in cells indicates exceedance of MAI in percentages of MAI. They are not shown for 2015-2016 due to changed methodology from 2017 assessment.

	Classification of achieved reduction of TP								
Baltic Sea sub-basin	**TP2015**	**TP2016**	**TP2017**	**TP2018**	**TP2019**	**TP2020**	**TP2021**	**TP2022**	**TP2023**
Bothnian Bay			2						
Bothnian Sea									
Baltic Proper			97	93	92	88	83	79	61
Gulf of Finland			56	22	38	38	40	38	35
Gulf of Riga			30	18	18	15	11	6	5
Danish Straits									
Kattegat									
Baltic Sea			38	31	29	28	24	21	17

4.3 Discussion text

The following table summarises main findings for the assessment of MAI2023 (data from 1995-2023) on airborne, waterborne and total nitrogen and phosphorus inputs to the Baltic Sea and its sub-basins. In the updated 2021 BSAP (in accordance with BSAP2013) there where reduction requirements to fulfil MAI for total nitrogen for Baltic Proper, Gulf of Finland and Kattegat and for total phosphorus for Baltic Proper, Gulf of Finland and Gulf of Riga.

Evaluation of MAI fulfilment takes the uncertainty on inputs into account. Only significant changes and trends are mentioned in the table below. The mentioned reference period is 1997-2003.

For all sub-basins there is a significant decrease in airborne inputs since the reference period, 37% on average. The average annual decrease in airborne inputs is higher during 2017-2023 (in average 2.9% per year) as compared with the decrease after the reference period (in average 1.6% per year).

HELCOM PLC Assessment unit name (and ID)	Threshold value achieved/failed	Distinct trend between current and previous assessment	Description of outcomes, if relevant
Bothnian Bay	Achieved for TN and TP	No changes	In 2023 estimated inputs of TN and TP were 93% and 96% of the respective MAI. In 2023 both total TN (18%) and TP (17%) inputs were lower compared with the reference period. Reduction in airborne TN inputs accounts for 33% of the total reduction in TN inputs since the reference period. Since 2008 breakpoint in the time series there is a decrease in total nitrogen inputs (12%) while TP inputs steady decreased (12%) since 2002

			breakpoint. Waterborne TN inputs have decreased since 2008 with 10% (after increasing 9.3% until 2008), while the corresponding TP inputs decrease 12% since 2002.
Bothnian Sea	Achieved for TN and TP	No changes	In 2023 estimated total inputs of TN and TP were 84% and 81% of the respective MAI. In 2023 both total TN (26%) and TP (24%) inputs were lower compared with the reference period. Reduction in airborne TN inputs accounts for 54% of the total reduction in TN inputs since the reference period. There is a decrease in total TN inputs with 19% since 2003 breakpoint, while TP inputs steady decreased (24%) since 1995. Waterborne TN inputs have decreased since 2003 with 21% but increased significantly from 1995-2003 9.3%), while the corresponding TP inputs decreased (28%) steadily since 1995.
Baltic Proper	Failed for TN and TP	No changes	In 2023 estimated total inputs of TN and TP were 124% and 161% of the respective MAI. In 2023 TN inputs has not changed significantly since the reference period while TP inputs were 35% lower. Reduction in airborne TN inputs accounts for all the total reduction in TN inputs since the reference period. Since 2009 breakpoint there is a significant increase (9.3%) in total nitrogen inputs while TP inputs are significantly decreasing (32%) after 2013 breakpoint. Waterborne TN inputs have increased since 2009 (21%), while the corresponding TP inputs decreased (37%) steadily since 2013.
Gulf of Finland	Failed for TN and TP	No changes	In 2023 estimated total inputs of TN and TP were 123% and 135% of the respective MAI. In 2023 for total TN inputs no significant change was detected compared with the reference period while TP inputs were 48% lower. Airborne TN inputs were although reduced with 33% since the reference period. Reduction in airborne TN inputs accounts 100% for reduction in TN inputs since the reference period. There is no trend in total TN inputs since 2017 breakpoint, and for TP since 2012 but TN inputs in 2017-

			2023. TP inputs during 2012-2022 is significantly lower (49%) than during 1995-2011. Waterborne TN and TP inputs show a corresponding development as the total inputs.
Gulf of Riga	Failed for TN and for TP not possible to justified due to statistical uncertainty on inputs	No change for TP	In 2023 estimated total inputs of TN and TP were 104% and 105% of the respective MAI. In 2023 total TP inputs were 33% lower compared with the reference period but no changes were assessed for total TN inputs. Airborne TN inputs were although reduced with 34% since the reference period. Reduction in airborne TN inputs accounts 100% for reduction in TN inputs since the reference period. TP inputs were reduced steadily (33%) since 1995. Waterborne TP inputs show a corresponding development to their total inputs. In 2023 waterborne TN input increased significantly (20 %) since the reference period and significantly with 33% since 2012 breakpoint corresponding to an annual increase with 3.0%/Y.
Danish Straits	Achieved for TN and for TP	No changes	In 2023 estimated total inputs of TN and TP were 88% and 75% of the respective MAI. In 2023 both total TN (23%) and TP (22%) inputs were lower compared with the reference period. Reduction in airborne TN inputs accounts for 76% of the total reduction in TN inputs since the reference period. Since 2014 there is no trend in total nitrogen inputs while TP inputs show a steady decrease (17%) since 2000, but with a lower annual rate than in 1995-1999. Waterborne TN and TP inputs show a corresponding development to their total inputs.
Kattegat	Achieved for TN and TP	No changes	In 2023 estimated total inputs of TN and TP were 92% and 85% of the respective MAI. In 2023 both total TN (26%) and TP (20%) inputs were lower compared with the reference period. Reduction in airborne TN inputs accounts for 46% of the total reduction in TN inputs since the reference period. Since 2012 breakpoint there is decrease with 15% in total TN inputs while total TP inputs decreased steadily since 1995 with 20%. Waterborne TN inputs have a minor (4.6%) but significant

			decrease since 2011, while waterborne phosphorus inputs decreased steadily (21%) since 1995.
Baltic Sea	Failed for TN and TP	No changes	In 2023 estimated total inputs of TN and TP were 111% and 117% of the respective MAI. In 2023 both total TN (11%) and TP (33%) inputs were lower compared with the reference period. Reduction in airborne TN inputs accounts for 87% of the total reduction in TN inputs since the reference period. Since 2016 there is no trend in total nitrogen inputs, while TP inputs show a steady decrease (33%) since 1995. There is no trend in waterborne TN inputs since 2016, but the level is higher than the previous 5 years, while the corresponding TP inputs decreased steadily since 1995.

TN = total nitrogen; TP = total phosphorus. Previous assessment is MAI2022.

5 Confidence

The confidence of the assessment is affected by the certainty of the quality of the nutrient input data, the trend in the inputs and the uncertainty of MAI, in relation to how far the nutrient inputs are from MAI:

The overall confidence of the assessment is high, but can be further detailed as:

- High for sub-basins with nutrient reduction requirements: nitrogen to Kattegat, Gulf of Finland and Baltic Proper and phosphorus to the Baltic Proper, Gulf of Finland and Gulf of Riga.
- Moderate for phosphorus to Bothnian Sea and nitrogen to Danish Straits due to limitations in the MAI calculation.

6 Drivers, Activities, and Pressures

Drivers are often large and disparate concepts and thus hard to quantify as they may for example relate to broad societal changes, globalisation, political will, regulation, or consumer practices. Changes in such drivers can alter human activities and thereby result in changes in pressures. Quantifying drivers directly, however, is not straightforward and proxies indicative of the impact of drivers on human activities are often the only viable option. For HOLAS 3 initial work was carried out to explore Drivers (and driver indicators) to evaluate how such information can be utilised within such management frameworks as DAPSIM. Although it is recognized as only addressing a small portion of the drivers (via proxies) of relevance for eutrophication, wastewater treatment (Drivers and driver indicators for Wastewater Treatment) and agriculture (Drivers and driver indicators for Agricultural Nutrient Balance) have been explored in pilot studies for HOLAS 3.

Diffuse sources constitute the highest proportion of total nitrogen (nearly 50%) and total phosphorus (about 56%) inputs to the Baltic Sea (HELCOM 2022a). For total nitrogen, atmospheric deposition on the sea has the second highest share (24%) followed by natural background loads (20%) and point sources (9%). Natural background loads have the second highest share of total phosphorus inputs to the Baltic Sea (20%), followed by point sources (17%) and atmospheric deposition (7%). Point sources include activities such as municipal wastewater treatment plants, industrial plants and aquacultural plants and diffuse sources consist of natural background sources, and anthropogenic sources such as agriculture, managed forestry, scattered dwellings, storm waters etc.

Furthermore, developing an overview of such components and the relevant data to be able to better quantify the linkages within a causal framework provides the opportunity for more informed management decisions, for example targeting of measures, and can thereby support the achievement of Good Environmental Status. The MAI indicator presented here addresses the inputs of nutrients to the Baltic Sea (i.e. pressures) and a number of status indicators exist, thus an improved understanding of the relevant components related to drivers and activities (their data sources and how to evaluate them) can significantly improve the overall understanding of eutrophication and appropriate management of the matter.

Table 7. Brief summary of relevant pressures and activities with relevance to the indicator.

	General	**MSFD Annex III, Table 2a**
Strong link		Substances, litter and energy - Input of nutrients – diffuse sources, point sources, atmospheric deposition
Weak link		Substances, litter and energy - Input of organic matter – diffuse sources and point sources

7 Climate change and other factors

The current knowledge on the response of nutrient inputs to climate change was included in the recent HELCOM Climate Fact Sheet (2024). It was concluded that river runoff is expected to be increased from the northern part of the catchment while most likely southern catchments will be dryer. This will potentially lead to corresponding changes in loads from diffuse sources. Especially for phosphorus, effects from measures may have delayed response in the ecosystem due to excessive storage in soils and, in some cases, lakes. Scenario simulations demonstrate that land-based nutrient management will have a greater effect on nutrient loads than greenhouse gas emissions. There are still substantial knowledge gaps, such as poor quantitative knowledge of the response of terrestrial biogeochemical processes to climate change. Another main uncertainty is how the anthropogenic drivers (and activities) will change in response to climate change and socioeconomic development.

8 Conclusions

A significant reduction of nutrient inputs has been achieved for the whole Baltic Sea. This assessment shows that the normalized total input of nitrogen[3] was reduced by 11% and phosphorus by 33% since the reference period (1997-2003) and 2023 (Results figure 1). In 2022, the corresponding reductions were 12% for total inputs of nitrogen and 32% for total phosphorus. The maximum allowable input (MAI) of nitrogen in this period was fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat (Key message figures 1 and Results tables 2a and 2b), and not fulfilled in the remaining sub-basins and to the Baltic Sea. MAI for phosphorus input was also fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat. In Gulf of Riga the fulfilment of MAI for phosphorus cannot be judged taking statistical uncertainty on inputs into account. In the remaining sub-basins and for the Baltic Sea MAI was not fulfilled for total phosphorus. Recent trend in waterborne nitrogen input shows no trend to the Baltic Sea, Gulf of Finland, and Danish Straits, a decrease to Bothnian Bay, Bothnian Sea, and Kattegat, but an increase to Baltic Proper (with 21% since 2009) and to Gulf of Riga (33% since 2012).

8.1 Future work or improvements needed

The indicator was extended in 2021 by assessing trends and shares of both waterborne nitrogen and phosphorus and airborne nitrogen besides the assessment of total inputs of nitrogen and phosphorus. Further comparison with every former MAI assessment is included in the indicator. Since MAI2022 testing for trends since the reference period and after the last breakpoint is included, but any trend since 1995 has been excluded. Also an extra table with trend estimates for total nitrogen including trends in air- and waterborne inputs per sub-basin was introduced in chapter 4. Furthermore, an extra table is included in the Key Message. In MAI2023, the trend expressed as changes per year has been included in chapter 4, and explanatory text was added in chapter 4.

The indicator assesses MAI with the level of detailed originally developed and adopted in the 2021 Baltic Sea Action Plan.

There is no short-term need for future development of the indicator besides considering how to take significant trends in flows in the normalization procedure into account.

[3] Total inputs of nitrogen and phosphorus are the sum of the respective waterborne inputs (which consists of riverine inputs and direct inputs (point sources discharging directly to the sea) and airborne inputs. Nitrogen and phosphorus inputs include all fractions of these nutrients (dissolved, particulate, inorganic and organic).

9 Methodology

9.1 Scale of assessment

Nutrient input data have been compiled in accordance with PLC-water guidelines for the following nine PLC sub-basins: Bothnian Bay, Bothnian Sea, Archipelago Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, Western Baltic, the Sound and Kattegat. The boundaries of the sub-basins coincide with the main terrestrial river basin catchments.

The BALTSEM model has divided the Baltic Sea into seven sub-basins in accordance with natural marine boundaries and hence the MAIs have been calculated for the following seven sub-basins: Kattegat, Danish Straits, Baltic Proper, Bothnian Sea, Bothnian Bay, Gulf of Riga and Gulf of Finland. In the BALTSEM sub-division, the Bothnian Sea includes the Archipelago Sea and the Danish Straits combine Western Baltic and the Sound.

The entire Baltic Sea is covered by the assessment.

9.2 Methodology applied

Data sources

The HELCOM Contracting Parties annually report waterborne inputs of nitrogen and phosphorus from rivers and direct point sources to Baltic Sea sub-basins. Data on atmospheric emissions and monitored atmospheric deposition are submitted by countries to the Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP), which subsequently compiles and reports this information to HELCOM. In accordance with Recommendation 37-38-1 Rev1 “Waterborne pollution input assessment (PLC-Water)” (HELCOM, 2022), sources of nutrient inputs are assessed every six years.

Nutrient input data can be viewed in HELCOM PLC reports (e.g. HELCOM 2013d, HELCOM 2023) and in the annual Baltic Sea Environmental Facts sheet (e.g. Svendsen & Gustafsson, 2025) and from the HELCOM PLUS database.

Trend analysis and statistical processing

Annually reported data on riverine and directs inputs are quality assured and approved by national data reporters and data assurers. Assessment dataset for 1995-2023 based on the reported data was established after expert reviewing and filling data gaps in. Riverine data are flow normalized for individual rivers with complete time series from 1995-2023. Direct inputs from point sources are not normalized. Input from unmonitored areas and rivers with incomplete time series are aggregated and normalized for sub-basins. EMEP delivered actual and weather-normalized annual nitrogen deposition data. For information about normalization of airborne and flow normalization of waterborne input data, see chapter 10 and annex 6 of PLC-water guidelines (HELCOM 2022) and Larsen and Svendsen (2021).

An elaborate scheme for trend analysis has been developed during the past decade (Larsen & Svendsen, 2021). There are dual purposes of the trend analysis: i) to compute a robust estimate of the change in nutrient inputs during the past decades and ii) to obtain robust estimates of the magnitude and uncertainty of current nutrient inputs. Only normalized data is used in the trend analysis. Many of the nutrient input time-series cannot be described accurately by a linear trend. For example, in several cases nutrient inputs decrease faster in the beginning of the time-series than in more recent years, there are cases with significant jumps due to, e.g. point sources removal, and yet others with data quality issues in the early part of the time-series. To accommodate these cases, an elaborate procedure is used to, in effect, split the time-series into segments by at least 5 years length using breakpoint analyses (see assessment protocol table 1 below), and perform linear trend regression on the segments. Trends that are not significant are disregarded and the relevant part of the time-series will be described by the mean value. The methods are described in detail in Larsen & Svendsen (2021) and HELCOM (2022).

Changes in nutrient inputs are substantiated on two time-scales, i) as change since the reference period (1997-2003) and ii) since the last breakpoint in the time series (recent trend), where last breakpoint can occur before or after the reference period. For time series with significant trend but no breakpoint “latest” trend covers the whole time series. How these changes are defined in relation to the complex trend analysis methodology are indicated in Results figures 2a-e. In addition, to estimate the magnitude of the change, adequate statistical analysis is performed to ensure which changes are significant. This analysis is also described in detail in Larsen & Svendsen (2021) and HELCOM (2022).

Assessment Protocol Table 1. The process for identifying breakpoints, testing for significant slopes and fitting constants (no significant slopes) and regression parameters (significant slopes) in a time series. From Larsen & Svendsen (2021).

1. step	2. step	3. step	4. step
A significant breakpoint	Test for additional breakpoints in each segment	Test for significant slopes in the segments	Fit a constant in segments with a non-significant slope. Fit regression parameters in the rest of the segments.
No breakpoint	Fit a constant for the whole time series		

The evaluation of MAI fulfilment is based on comparing MAI for each sub-basin of the Baltic Sea with the trend estimated normalized annual total nitrogen and phosphorus inputs in 2023 including and estimated uncertainty on these inputs (Results tables 2a-b) based on the most recent segment of the time series and the estimated value of the most recent year (Larsen & Svendsen 2021). In the first and second evaluation of MAI fulfilment uncertainty of average of respectively 2010-2012 and 2012-2014 normalized inputs was estimated from the variation of the three-year inputs around the average.

The testing for significant difference in the trend estimated input and inputs in the reference period (average of normalized annual inputs 1997-2003) is done by calculating 95 % confidence interval on the average normalized inputs in the reference period and the corresponding interval around the estimated inputs for the latest year inputs and testing if the two confidence intervals are statistically different (Larsen & Svendsen, 2021).

Trend with breakpoint analyses is also performed for airborne total nitrogen and for waterborne total nitrogen and total phosphorus inputs (Results figures 2c, 2d and 2e).

9.3 Monitoring and reporting requirements

Monitoring methodology

Waterborne inputs

Contracting Parties measure water flow and concentrations of selected parameters in riverine water and point source discharges. Estimates of inputs from unmonitored areas are based on modelling including information of point sources discharges (monitored or estimated). These data are used to calculate total annual inputs to the sea. These measurements and estimates are carried out by the Contracting Parties. The methods for monitoring and calculating waterborne pollution inputs are described in the PLC-water guidelines (HELCOM, 2022) last updated by the PLC-8 project.

An overview of agreed monitoring of nutrient inputs is also described in the HELCOM PLC-water guidelines (HELCOM 2022) and monitoring data are available from HELCOM PLUS database (HELCOM PLC) at http://nest.su.se/helcom_plc/).

Atmospheric inputs

Atmospheric emissions and measured atmospheric deposition are reported by countries to the Co-operative Programme for Monitoring and Evaluation of the Long-Range Transboundary Air Pollutants in Europe (EMEP), which compiles and reports to HELCOM. EMEP models the deposition of nitrogen input based on emission measurements and estimates and information on meteorological parameters. The results of the EMEP model are routinely compared to available measurements at EMEP and HELCOM stations. The deposition of phosphorus is not modelled but based on measurements from (rather few) monitoring stations, and a fixed deposition rate of 5 kg P per km^2 has been used since 2014 in PLC assessments (e.g. HELCOM 2014b; HELCOM 2015 and following assessments). Details of the monitoring activities and the model are available in the HELCOM Monitoring Manual for nutrient inputs from atmosphere.

Current monitoring

Waterborne inputs

Inputs from large rivers are monitored and the measurements used for calculating inputs are reported. Inputs from smaller unmonitored rivers are generally estimated by models. Inputs from point sources (municipal wastewater treatment plants, industry and aquaculture) discharging directly to the Baltic Sea are reported separately.

Monitoring table 1a. Numbers of rivers, monitored area (2023) and percentages of waterborne nitrogen inputs that were monitored, unmonitored, and direct point source discharges of total waterborne nitrogen inputs to the Baltic Sea sub-basins.

Sub-basin	Number of rivers	Monitored area (km²)	Monitored area (% of total area)	Total N monitored (%)	Total N unmonitored (%)	Total N direct (%)
Bothnian Bay	21	232 900	88	78	16	6
Bothnian Sea	20	192 500	85	65	30	5
Baltic Proper	46	514 900	90	84	14	2
Gulf of Finland	23	401 800	96	78	13	9
Gulf of Riga	7	121 100	88	86	14	0
Danish Straits	113	14 100	52	41	50	9
Kattegat	85	76 300	88	66	30	4
Baltic Sea	**315**	**1 553 600**	**90**	**77**	**19**	**4**

Monitoring table 1b. Numbers of rivers, monitored area (2023) and percentages of waterborne phosphorus inputs that were monitored, unmonitored, and direct point source discharges of total waterborne phosphorus inputs to the Baltic Sea sub-basins.

Sub-basin	Number of rivers	Monitored area (km²)	Monitored area (% of total area)	Total P monitored (%)	Total P unmonitored (%)	Total P direct (%)
Bothnian Bay	21	232 900	88	83	14	3
Bothnian Sea	20	192 500	85	59	35	6
Baltic Proper	46	514 800	90	86	11	3
Gulf of Finland	23	401 800	96	81	11	8
Gulf of Riga	7	121 100	88	88	11	1
Danish Straits	113	14 100	52	38	42	20
Kattegat	85	76 300	88	67	26	7
Baltic Sea	**315**	**1 553 600**	**90**	**78**	**17**	**5**

Monitoring tables 1a and 1b show that about 90% of the total Baltic Sea catchment area is covered by monitoring based on more than 300 monitoring stations. For six of the seven sub-basins between 85% and 96% of the catchment areas are monitored, and these catchments are covered by monitoring in mainly large rivers. For Danish Straits only about

50% of the catchment is monitored due to many small river catchments even though 113 monitoring stations or more than one third of all river monitoring stations in the Baltic Sea catchment area are situated in the catchment.

Monitoring tables 1a and 1b also show that estimated/calculated inputs from unmonitored areas constitute 19% of total nitrogen and 17% of total phosphorus waterborne inputs to the Baltic Sea.

Details of the monitoring activities are available in the HELCOM Monitoring Manual for land-based sources.

Atmospheric inputs

Details of the monitoring activities and the model are available in the HELCOM Monitoring Manual for nutrient inputs from atmosphere and Monitoring table 2 gives an overview of the number of nitrogen monitoring stations located at the Baltic Sea used to compare model and monitored nitrogen deposition.

Monitoring table 2. Number of monitoring stations situated close to the Baltic Sea used for measuring wet and dry deposition of nitrogen compounds in 2021.

Sub-basin	**Wet deposition of N**	**Dry deposition of N**
Bothnian Bay	2	0
Bothnian Sea	2	1
Baltic Proper	6	6
Gulf of Finland	3	2
Gulf of Riga	0	0
Danish Straits	5	5
Kattegat	2	3
Baltic Sea	**20**	**17**

Description of optimal monitoring

Waterborne inputs

Guidelines for sampling discharges from point sources and inputs via rivers are given in the PLC-water guidelines. For riverine inputs, as a minimum 12 samples should be taken each year at a frequency that appropriately reflects the expected river flow pattern. If more samples are taken (e.g. 18, 26 or more) and/or the flow pattern does not show a major annual variation the samples can be more evenly distributed during the year. Overall, for substances transported in connection with suspended solids, lower bias and better precision is obtained with higher sampling frequency.

For rivers with hydrological stations the location of these stations, measurement equipment, frequency of water level and flow (velocity) measurement should at least follow the World Meteorological Organization (WMO) Guide to Hydrological Practices (WMO-No. 168, 2008) and national quality assurance (QA) standards.

Preferably the discharge (or at least the water level) should be monitored continuously and close to where water samples for chemical analyses are taken. If the discharges are not monitored continuously the measurements must cover low, mean and high river flow rates, i.e. they should as a minimum reflect the main annual river flow pattern. Further details are provided in the PLC-water guidelines (HELCOM, 2022).

Atmospheric inputs

Collection of air emission data and modelling atmospheric deposition are coordinated by EMEP. There are rather few stations located at the coast or on small islands in the Baltic Sea, and not all stations are measuring all components. Further, only some stations have long time series. Not all national monitoring stations are included in the list of "HELCOM stations" but could be used by EMEP. There are also some problems with the representativeness of the stations, i.e. rather many in the south-western part of the Baltic Sea but few in the eastern and northern parts that cause challenges when verifying the EMEP model results. For phosphorus it is especially important to establish a more extensive and representative monitoring station network, as there are no models developed to estimate the atmospheric phosphorus deposition. Thorough analysis of the monitoring data would improve the understanding of the development in the atmospheric deposition and also offer recommendations on how to improve and possibly expand monitoring.

10 Data

The data and resulting data products (e.g. tables, figures and maps) available on the indicator web page can be used freely given that it is used appropriately and the source is cited.

Data on air- and waterborne nutrient inputs from 1995 to 2023 are used in this indicator. Data reporting has not been perfect, and some few gaps exist in the dataset. For waterborne inputs, the PLC-6 project corrected suspicious data and filled in data gaps for 1995-2014 to establish a complete and consistent dataset. 2015- 2023 data have been added and assessed by BNI, Stockholm University and DCE, Aarhus University under the PLC-7, PLC-8 and PLC-9 projects. Gaps in time series of national air emissions have also been corrected by EMEP experts.

Data on actual (non-normalized) riverine flow as well as atmospheric and waterborne inputs of nitrogen and phosphorus are available at the link below:

Data: Inputs of nutrients to the sub-basins - 2022 indicator version

Waterborne inputs

The dataset behind the present assessment was compiled by the PLC-9 project and updated by DCE, Aarhus University and BNI, Stockholm University in cooperation with Expert Group on Reduction Scheme Core Follow-up, RedCore EG.

Data on waterborne inputs, water flow and retention are reported by Contracting Parties to the PLC-Water database (PLC-PLUS) reporting WEB application. The data are verified and quality assured using the PLC-PLUS water database verification tools and national expert quality assurance.

There are gaps in the time series of national inputs in the PLC-water database. Therefore, DCE and BNI amended the dataset filling in missing and correcting suspicious data to establish an assessment dataset which then was checked and approved for use in this indicator by the Contracting Parties. A description of the methods used to fill data gaps in is given in chapter 1.2 in BSEP 141 (HELCOM, 2013d) and documentation prepared by the PLC-5.5 project.

Data on water- and airborne inputs are available from 1995-2023 and cover the entire drainage basin of the Baltic Sea.

Inputs are calculated from measurements taken from monitored rivers and point sources as well as calculated estimates or modelled inputs from unmonitored areas. Quality assurance guidelines for sample analysis are described in the PLC-water guidelines and intercalibration activities are carried out periodically. The most recent intercalibration activity with published results was carried out under the PLC-9 project (in Lassen & Larsen, 2025).

No official information about the uncertainty of inputs of nutrients or organic matter or flow data has been reported to HELCOM yet, but uncertainty estimates are included as a request to be reported by the Contracting Parties in the PLC-water guidelines. The uncertainty of annual total waterborne nitrogen and phosphorus inputs are computed for each individual sub-basin based on statistical analysis of input trends for the period 1995-2023, and examples given in Larsen & Svendsen, 2021.

Airborne inputs

Atmospheric input data for all Baltic Sea sub-basins are available for the period 1990-2023. Atmospheric transport and deposition of nitrogen compounds are used for modelling atmospheric deposition to the Baltic Sea based on official emission data reported by EMEP Contracting Parties and expert estimates. Atmospheric input and source allocation budgets of nitrogen (oxidized, reduced and total) to the Baltic Sea sub-basins and catchments were computed using the latest version of EMEP MSC-W model. The EMEP MSC-W model is a multi-pollutant, three-dimensional Eulerian model. It takes into account processes of emission, advection, turbulent diffusion, chemical transformations, wet and dry depositions, and inflow of pollutants into the model domain. It is driven by meteorological data from the Integrated Forecast System of ECMWF (European Centre for Medium Range Weather Forecasts). A comprehensive description of the model and its applications is available on the EMEP website.

Compared to the first evaluation of MAI fulfilment (Svendsen et al. 2015), in 2016 EMEP revised the modelled nitrogen air deposition to the Baltic Sea for 1995-2012. This resulted in an increase of the annual deposition to the Baltic Sea of 16 to 23%. The increase of annual nitrogen deposition to the individual sub-basins was between 9 and 27%. The EMEP deposition model was further updated after the second MAI assessment (HELCOM, 2018). The update mainly concerned changing of the deposition grid resolution from 50km*50km to 0.1°*0.1° (approx. 11km*6km grid cells in the Baltic Sea). The higher resolution was applied for computation of the annual nitrogen deposition 2000-2017, and for the present MAI assessment 1995-2023 (Gauss et al., 2025). Also, the whole time series of nitrogen emission data is updated annually, and this yearly emission data for 1990-1994 was also available. For years since 2000 the data from FMI on ship emissions have replaced former ship emission data in the deposition calculation. The update of the model, revised reported emission data and use of weather data in the normalization procedure (section "Airborne Inputs" under chapter "Data and updating") resulted in markedly changed deposition data compared to the previous reporting. Deposition on the Baltic Sea in the reference period (1997-2003) was nearly 294 000 tonnes/y nitrogen in the latest EMEP estimate, compared to 227 000 tonnes/y nitrogen previously estimated, or 29.3% higher than calculated for the BSAP 2013. The nitrogen deposition in the reference period showed the highest change in the Kattegat (41%)and Gulf of Finland (+32%) and the lowest in the Gulf of Riga (16%).

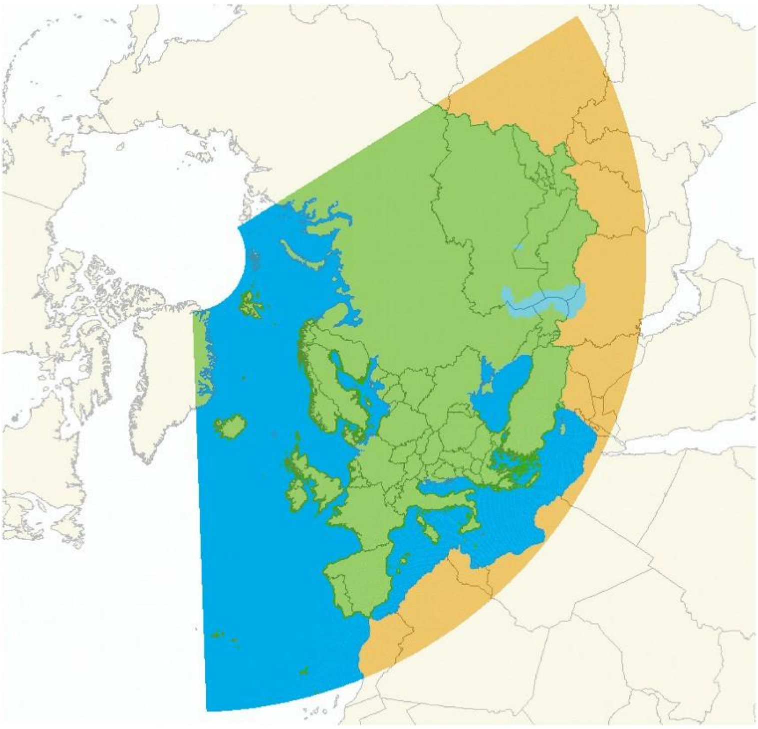
Atmospheric deposition of oxidized and reduced nitrogen was computed for the entire EMEP domain, which includes the Baltic Sea basin and its catchment (Data figure 1).

Calculations are done annually on data from two years prior to the calculations. For further details see the annual report by EMEP to HELCOM (Gauss et al., 2025). Data on air emissions and atmospheric deposition are maintained by EMEP and can be accessed via the EMEP website.

The results of the EMEP MSC-W model are routinely compared to available measurements at EMEP and HELCOM stations. The comparison of calculated versus measured data indicates that the model predicts the observed air concentrations of nitrogen within an accuracy of approximately 20-30%. Further work is required on reducing uncertainties in emission data and better parameterization of physical processes in the EMEP MSC-W model to increase accuracy in future model estimates.

No official information about the uncertainty of provided nitrogen emission data has been sent to EMEP from neither EMEP nor HELCOM Contracting Parties, and consequently further work on emission uncertainty is essential. Submitted emissions data are passing through QA/QC procedures and stored in the EMEP Centre for Emission Inventories and Projections CEIP in Vienna, Austria. Reviews about the consistency, comparability and trends of national inventories are available at http://www.ceip.at/. There are gaps in time series of national emissions that have to be corrected by experts to make the time series complete.

There are limited data on phosphorus deposition and no emission data for the modelling work has been available for evaluation. For most countries, measurements only covered wet deposition and there was a lack of data on particulate and dry deposition. A fixed deposition rate of 5 kg P per km^2 to the Baltic Sea has been used since the PLC-5.5 assessment (HELCOM 2014b, HELCOM 2015). The estimates of phosphorus deposition rates are mainly based on the data from monitoring stations close to the coastline of the Baltic Sea. But there are very few monitoring stations on small islands in the Baltic Sea, and therefore the use of the data mainly from stations on land might lead to an overestimation of deposition. Many monitored concentrations (dry and wet deposition) are very low and close to detection limit. Therefore, the atmospheric phosphorus deposition data and the applied deposition rate is rather uncertain, for the whole Baltic roughly ±50% and for minor sub-basins such as Gulf of Riga and The Danish Straits even higher uncertainty exists. As atmospheric deposition on average only constitutes 9% of total phosphorus inputs, these uncertainties are less critical than in the case of atmospheric deposition of nitrogen, which on average constitutes nearly 25% of total nitrogen inputs to the Baltic Sea.



Data figure 1. The EMEP model domain used for computations on atmospheric deposition.

Arrangements for updating the indicator

Annual total waterborne inputs of nitrogen, phosphorus and their fractions are reported every year by the HELCOM Contracting Parties and compiled by the PLC Data Manager at the HELCOM Secretariat. The data collection is based on a combination of monitored data (measurements at monitoring stations close to river mouth and at point sources) and estimates of inputs from unmonitored areas.

The HELCOM PLUS is a modernized PLC database including QA facilities when uploading, and inserting data, and which allow data reports, quality assures from the Contracting Parties improved access to the waterborne input data. Further assessment dataset will be available in an assessment database under development.

Data on air emissions are reported to EMEP, which subsequently models the atmospheric deposition to the Baltic Sea. EMEP hosts the emission and deposition data, which can be accessed via their website. EMEP is contracted by HELCOM to provide selected data products on an annual basis.

The Baltic Nest Institute (BNI), Sweden, and Danish Centre for Environment and Energy (DCE), Aarhus University, Denmark have in cooperation with Reduction Scheme Core Expert Group, EG RedCore elaborated the present core pressure indicator on nutrient inputs.

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11 Archive

This version of the HELCOM core indicator report was published in 2026:

HELCOM core indicator on inputs of nutrients for period

1995-2023 (pdf)

Earlier versions of the core indicator:

HELCOM Core indicator on inputs of nutrients for period 1995-2022 (pdf)
HELCOM Core indicator on inputs of nutrients for period 1995-2021 (pdf)

HELCOM core indicator on inputs of nutrients for period
1995-2020 (pdf)
HELCOM core indicator on inputs of nutrients for period 1995-2019 (pdf)
HELCOM core indicator on inputs of nutrients for period
1995-2018 (pdf)
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13 Other relevant resources

No additional information if required for this indicator.