Applied methodology for the PLC-8 assessment

Baltic Marine Environment
Protection Commission

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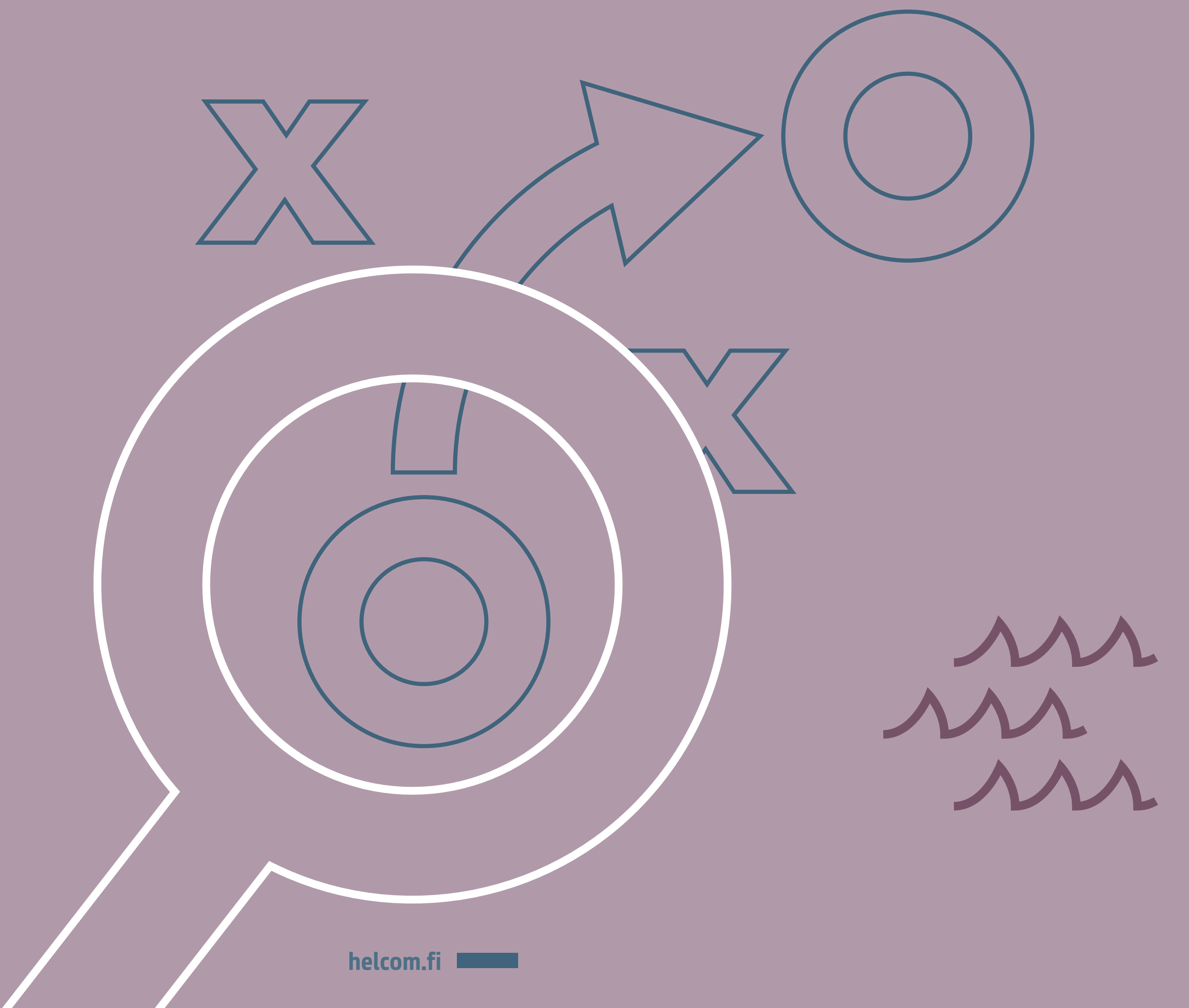

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1. Introduction

The PLC guidelines include e.g. guidance on sampling methodology, how to calculate loads from points and diffuse sources, quantification of inputs from unmonitored areas, quantifying uncertainty on flow and inputs, how to conduct source apportionment etc. for PLC assessment.

The first methodology was elaborated under the PLC-6 project. The report was based on a questionnaire filled in by the Contracting parties (the nine member countries of HELCOM). When countries have used methods described in the PLC guidelines, they could refer to these, otherwise they should provide a short description of the methodology. A revised version on applied methodology was elaborated under the PLC-7 project by requesting Contracting Parties to make updates of description of their methodologies. Under the current PLC-8 project Contracting Parties again have been requested to update their applied methodology during 2023 and 2024, and this report is then an updated of the "Applied methodology report for PLC 7"[1]

The report contains the reported methodology sorted by country. The following methods were included in the questionnaire on PLC-6 assessment methodology:

1. Calculation of flow and loads (rivers, direct point sources):
2. Inputs from unmonitored areas:
3. Source apportionment (load and source-oriented approach):
4. Retention:
5. Transboundary inputs:
6. Uncertainty on flow, loads, unmonitored and total inputs and on sources

The report includes an overview of the reported methodologies and a summary with remarks and discussion on the applied methodologies including the comparability of the results from the used national methods and some identified shortages.

It also includes an annex with details on the models used by contracting parties as a standardized overview on main in-data and out-data, resolution of these data and model resolution. The annex is elaborated by Michal Pohl, Swedish Agency for marine water and management (SWAM), based on inputs from PLC IG members.

[1] Svendsen, L.M (ed.) 2021. Applied methodology for the PLC-7 assessment. Helcom (2021), 59 p.

2. Overview on country methodologies

The table below provides an overview of the methodologies used by HELCOM Contracting Parties (besides EU). “Yes” in each cell indicates if a country reports and/or follows the principles/methodology described in the PLC guidelines. “No” indicates that a national method is applied or that the information is not reported.

After the overview table follows a chapter with summary remarks about the method applied. The chapter includes some identified shortages and need for improvement as indicated in *paragraphs with italic letters*.

The report then includes one chapter per country with the input elaborated by each country, and an annex with details on the models used by contracting parties as a standardized overview on main in-data and out-data, resolution of these data and model resolution.

	Flow/Load	Unmonitored areas	Source apportionment	Retention	Transboundary inputs	Uncertainty on inputs & sources
Denmark	Yes. Daily flow and daily concentration (linear interpolation). Chemi-cal and hydrological stations are coinciding. All point sources >30 PE calculated based on monitoring flow and concentrations (samp-ling frequency depends on PE). Scattered dwelling: estimated based on statistics on number of scattered dwelling, type of wastewater collection/treatment and coefficient of annual TN and TP losses for category. Storm waters: losses relate to statistics and amount of rain. Content of TP in 1 PE reduced gradually since 1990.	Yes National model estima-tes flow, diffuse losses of TN and TP (including scattered dwelling). Modelled run off in 0,5*0,5 km grid are aggregate to 3,351 catchments of in mean 13 km^2 polygons, and modelled monthly diffuse losses are calculated for the 3,351 catchments to estimated losses from the unmonitored areas. Diffuse losses for TN based on (soil type, % cultivation percentage, degree of drainage, monthly 10*10 grid precipitation, monthly average 20 *20 grid air temperature, calcula-ted nitrogen surplus (based on national data)) and TP (based on degree of drainage (from 30*30 m raster map), percentages of paved and of cultivated	Yes. Load and source-oriented approach according to guidelines and also estimated for unmonitored areas. Load oriented – agriculture estimated from loads. Minus other sources taking into account retention. Source oriented: Diffuse losses estimated with models (as for unmonitored areas). Atm. dep: calculated to inland surface waters based on monitored deposition on land (of TN and TP).	Yes Calculated for 21 large lakes individually with a national nitrogen model and individual for 600 larger lakes for phosphorus. Retention estimates for nearly 6,000 small ponds and lakes based on results from 16 monitored lakes). Retention f nitrogen is also estimated for streams wider than 2 m and for restored wetlands. Retention also taken into account for point sources in unmonitored areas.	Not relevant for Denmark.	Yes. Follows the Danish examples in the guideline.

		area, bank erosion, yearly precipitation and yearly deviation from mean annual precipitation 1991-2020, soil type (% sandy soil), percentages clay soil in 1-2 m depth, number of frost days). Point sources inputs (also monitored in unmonitored areas) added.				
Estonia	Yes. Daily flow daily concentration (linear interpolation). Point sources loads are based on quarterly reported flow average concentrations and flows.	Yes. National model (EstModel) divides Estonia in three catchments and eight sub-basins. Average specific run-off per catchment based on monitored part of the catchment based on the simple coefficient-based model	Yes Source oriented approach based on simple coefficients from the EstModel and for natural background losses natural concentrations.	Partly Retention in surface water is calculated using Michaelis-Menten equation approach (Michaelis & Menten, 1993). Retention on diffuse load is estimated as, where the value of the retention coefficient of the surface water is related to the estimated residence time of the nutrients in the waterbody. Retention on point sources are calculated by point source and by parameter (TN and TP) related to the time it	Yes. Narva River (border) assumed 1/3 of total load is Estonian.	Not quantified and reported.

				takes for the point source loads to reach the monitoring station and the time the retention of the point source load attain half of the maximum value of the retention coefficient.		
Finland	Yes Load: mean monthly concentration multi-plied by mean monthly flow and summed up. Flow proportional sampling. Point sources moni-tored.	Yes By extrapolation from monitored areas.	Yes Load and source-oriented approach according to guidelines with WSFS_VEMALA model. Natural background inputs and diffuse load based on monitoring 45 catchments. SOILN-N for TN estimates and ICECREAM model for TP loads from agricultural land. These results are extrapolated for whole Finland with various models.	Yes Use of WSFS-VEMALA model. National statistical modelling with mass balance approach using incoming and outflowing load in a sub-catchment, and load from point sour-ces, agriculture, fores-try, scattered dwel-lings, natural leaching and atmospheric deposition of N on lakes. Retention also taken into account for point sources. Retention is assumed negligible in unmoni-tored areas.	Yes Based on monitored inputs of the rivers Torne (also monitored by Sweden) and Vuoksi River and modelled nutrient inputs of the Seleznevka River.	Not quantified and reported.
Germany	Yes. Load: Daily flow and daily concentration (linear interpolation)	Yes. Annual reporting: Based on area proportion method	Yes. Source oriented approach using results of the empirical based	Yes The MoRE model provides riverine retention based on the	Yes Based on agree proportions of total TN	Estimated based on expert judgement.

	or mean monthly flow and monthly concentration depending on the Federal State. Direct point sources based on continuous flow measurements and non-continuous concentration.	based on the entire monitored area. Periodic reporting: Using the MoRE model to calculate pathway-oriented specific loads (coming from point and diffuse sources) entering surface waters and flow from unmonitored areas (summed up for the entire unmonitored area).	emission MoRE model. Calculations are pathway oriented and includes municipal wastewater treatment plants, industrial discharges, surface runoff, erosion, groundwater, tile drainage, atmospheric inputs on inland surface waters, stormwater sever and combines overflows. And small wastewater treatment plants. MoRE calculates on units of average size 130-150 km^2 based on drainage network (either administrative or hydrological). Natural background losses are modelled too.	MONERIS retention coefficients for TN and TP (Behrendt & Opitz (1999)).	(3.7 %) and TP (8.5 %) load in Oder.	
Latvia	Yes Load: mean monthly concentration multiplied by mean monthly flow and summed up. Point source load quantified based on data ion the “Udena-2”	Yes By extrapolation from monitored areas (area-proportion).	Yes. Source oriented approach based on land-use and simple export coefficients. Load-oriented follow guidelines. Losses from scattered dwelling and from atmospheric	Yes. Follows Behrendt & Opitz (1999) with retention coefficient for TN and TP depen-ding on discharge, areas on surface waters in the catchment.	Yes. Monitored monthly concentrations and extrapolated dischar-ges. Daugava loads divided between RU and BY taking into account catchments areas	Not quantified and reported for total loads. Estimates for flow for monitoring stations are quantified

	database with loads data reported by operators og WWTP.		deposition on inland surface waters are not quantified.		(based om the agreed percentages in the PLC--guidelines).	
Lithuania	Yes: Load: mean monthly concentration multiplied by monthly flow, where average monthly flow is obtained from daily flow and summed up. There are only few direct point sources Direct point source, data on loads reported by companies responsible those point sources. Periodic reporting: Load and flow are modelled with SWAT+ model (set up for entire Lithuania and described in the chapter from Lithuania).	Yes. Using areas proportion method using Minija River concentrations and flows. Periodic reporting: SWAT to model flow and concentrations and calculate load from unmonitored areas. For PLC-8 additional data to cover 2020 and 2021, and SWAT+ model run for 1994-2021 but using result from 2021. Results from one unmonitored area re-scaled to mirror the reported annual results.	Yes National model using average data 2007-2021. SWAT+-model use environmental data, climate, point source discharge, agricultural activities etc.) – all sources are simulated. Atmospheric deposition on inland surface waters and losses from scattered dwelling are not separated from other diffuse sources. .	Yes. Using SWAT+ model – calculate retention on all pollutants and sources – and include processes in river channels as sedimen-tation, resuspension, turn-over of nutrients, diffusion. Challenges with BALTLAND basin are solved by technical transferring upstream retention in Nemunas delta.	Yes. Use of monitoring data Nemunas, Neris and based on monitored data, and modelling for Venta, Barta and Leilupe and Pregolya. Inputs to Kaliningrad region through Matrosovka channel is estimate to amount 20% og Nemunas flow and load upstream the diversion point, but ids not included in the reporting.	Not quantified and reported.
Poland	Yes, partly Flow based on daily flow measurements. Nutrient concentration measured monthly (more frequent In Vistula and Oder). Load calculated as product	Yes. Use the area propor-tion methodology. The proportion between the unmonitored and monitored area of each river was used to calculate the load from	Yes. <u>Load-oriented approach</u>: It is assumed that retention coefficient of nutrients from different sources are not equal. Sources	Yes. Retention coefficients in monitored rivers is calculated based on the mass-balance methodology. Retention in unmon-itored part of a river	Yes <u>From Slovakia</u>: 100% based on monitored concentration and flows received from Slovakia. <u>From Ukraine</u>:	Not quantified and reported

	of monthly flow and monthly concentration. Point sources larger point sources need at least one measurement required – calculate load of the day and multiply with 365. For smaller WWTP (typical < 2000 PE) data from 193 WWTP >10,000PE and the TN/BOD_5 (0.274) and TP/BOD_5 (0.034) was used as input tp the small WWTP and reduction factors of 0.65 for TN and 0.35 for TP was applied. Further it is estimated that 5% of TN and 11% of TP total WWTP load, respectively are not included by the National Urban Wastewater Treatment Programme (KPOSK) Industries: Only data for plants in PRTR register are available which is plants with more than	unmonitored parts of river. The load from point sources located at unmonitored catchments was added to load in each catchment. For BAPLAND the load was extrapolated from 7 monitored rivers using the same proportion method.	have been divided in two groups: one group with the source discharging directly to surface waters (point sources and atmospheric deposition, the other group diffuse sources including scattered dwelling. overflows and natural background losses. Applying two scenarios. In scenario 1 retention coefficients for all sources in both groups, and scenario 2 all retention in group 1 is zero. Average of the two scenarios are used. Natural background losses: The losses are clearly separated from managed forestry and wastelands. 0.02 mg P/l is used for natural background concentration, while the nitrogen concentration depends	catchment was calcula-ted as proportional to the share of the unmo-nitored area of the entire catchment of that river catchment – but is only applied on the sources in the unmonitored part of a catchment	For on rivers based on monitored on Polish part, and from other rivers based on the proportion off catchment I Ukraine and using a unit load From Belarus: More or less as from Ukraine. Czech Republic: Polish monitoring at the border covering 75 % of the catchment in Czech Republic. Remaining contribution from CZ are not quantified. Germany: Load from Germany estimated based on fixed ratios of Oder total loads (3.66 % TN and 8.52 % TP).	

	50,000 kg N/y and 5,000 kg P/Y. Used information from official statistical database from about 2,500 municipalities. Loads from industrial plants are underestimated. Aquaculture: Information not public available. Based on a pressure database compiled for WFD implementation og using poof water permit indicates about 270 aquaculture facilities, and assuming standardize loss of 60 kg N and 9 kg P tonnes er tonnes produced fish respectively. Scattered dwellings: TN and TP load 4.4 kg/n and 0.8 kg P per person, statistics on number of not connected person and coefficient of TN and TP entering surface		on soil permeability from 0.15 mg N/l (highly permeable), 0,36 mg/l semi permeable and 0.60 mg N/l (poorly permeable) soils. For atmospheric deposition in natural background catchments a fixed literature value is applied (1.2 kg N/ha) Agricultural land: Monitoring in each catchment of nitrates and phosphates – monitored in a country wise groundwater and tile drainage water monitoring program (nitrate and phosphate) in mainly agricultural areas. Data only available for Vistula and Oder catchment. Flow from agricultural land: Estimation of losses are based on results of a statewide			

	waters according to HARP guidelines. Storm waters: Using HARP guidelines Using paved urban areas connected to combined sewer system, TN and specific TN and TP discharges from paved urban areas (14 kg N/ha and 1.2 kg TP/ha) Aquaculture sources: No fish feed data available. Use of standard units loads of 60 kg/N on fish and 9 kg/tons fish.		groundwater and tile drainage programme. Nitrogen data available for 2021 for phosphorus for 2021, 20016 and 2020 Load= average concentration time average flow multiplied by a correction factor to take into account other N and P compounds, and other correction done (se section 2.5 from Poland). For some minor catchment also used MONERIS modelling to estimate agricultural sources. Forestry and unmanaged land: Use of slope, permeability of soils, estimated N and P concentration in precipitation, flow weighted concentration from managed forestry.0,038 mg p/l			

			was used for all soil types, while nitrogen concentration depends on soil permeability from 0.31 mg N/l high permeable to 1.22 mg/l for poor permeability <u>Direct atmospheric deposition:</u> Based on monitoring from 22 monitoring stations TN and TP in precipitation and calculated for inland surface waters using extrapolation from monitoring points. <u>Scattered dwellings:</u> Se column “Flow/load” Number of persons not connected to WWTP are estimated for 2,500 municipalities. It is assumed that 90 % of total N and P loads generated discharged from untreated areas is generated by people in such areas using septic tanks and 10 % domestic treatment			

			plants. Unit loads based on data from 500 treatment plants is 13.78 g TN/day and 1.82 g P/day PE. The share of TN and TP reaching surface wasters are estimated by making an agricultural fertilizer balance estimating 1% of TN and 6% of TP ends up in surface water. Urban surface run off and combined sewer overflow: Includes storm overflows of combined sewer system and rainwater and snowmelt discharged from managed areas in Corine Land Cover category 1. For combine sewer overflows load were estimate from combined sewer length in total sewer systems from about 180 Polish cities with combined sewer with overflows.			

			Surface flow including stormwater drainage used concentration of 2.0 g N/l and 0.35 mg P/l from literature studies in surface flow waters and an assumed coefficient of 0.2 (20%) for runoff of water flow from urban areas. Interflow and ground flow Assumed accounting for 80% of the total flow. Reduction factors of 0.17 for TN and 0.68% for TP, respectively on the numbers mentioned for surface flow have been used and then natural background concentrations have been deducted. Source in monitored and unmonitored areas are estimated with exactly same methodology.			

			All land cover data are from Corine Land Cover 2018.			
Russia	Yes Load: mean monthly concentration multiplied by mean monthly flow and summed up. Direct point sources based on continuous monitoring (min 12 times per year).	Yes. Estimated using HYPE and FyrisNP model.	Yes. For big catchments using Institute of Limnological Loading Model. Model includes annual load, load from point sources, diffuse load from agriculture, diffuse emissions from land surface not affected by agriculture and atm. dep. HYPE og FyrisNP model used to assess source contribution in Leningrad region and smaller catchments in the watershed of Gulf of Finland. <u>Point source load</u>: state statistical data. <u>Natural and anthropogenic load</u> (excluding agriculture) specific concentrations in runoff from urban areas (scattered dwellings areas),	Yes. Follows Behrendt & Opitz (1999) method: See Russia formulas no. 5-6-7-8. Requires annual load from the catchment direct load to the lake, hydraulic load to the lake, lake percentage in the catchment, specific run-off.	Yes. Based on agree proportions used for PLC5.5.	Not quantified and reported.

			natural background areas and mixed area taking into area and runoff of each of these types. For small catchments load from scattered dwelling are estimated using a Swedish Environmental Protection Agency method. Atmospheric: TN zero, TP 3.2 kg/km^2. Agriculture diffuse loads: Formula 3 take into account N and P content I plough layer, organic and mineral fertilizer applied, field areas (per enterprise), coefficient related to uptake of organic and mineral fertilizer, nutrient outflow from plough layer, distance from agricultural areas to receiving surface waters, soils types, soil texture, land use			

			structure, status of applying BAT. <u>Background load</u>: Take into account coefficient for mass exchange with atmosphere, % lake area and retention factor.			
Sweden	Yes. Daily flow and daily concentration (from linear interpolation of monthly concentrations). WWTP >2,000 PE and industry are monitored loads (monitoring frequency depends on size). Smaller WWTP sources are estimated based on treatment metho-dology and number of person equivalents.	Yes. Main rivers (38) monitored to the mouths. Unmonitored area downstream monitored big rivers are estimate by area proportion. Minor rivers and coastal areas are estimated with weighted area-specific load estimated from similar rivers in the area.	Yes. <u>Source oriented</u>: HYPE-model calculate TN and TP loads to lakes and rivers for 39,653 sub-catchments. Includes inputs from point sources specifically calculate as daily means in 2021 and for diffuse sources (land use, leaching, stormwater, scattered dwellings, and atmospheric deposition on lakes). Land use leaching estimate from specific runoff and concentration in runoff for the current land.	Yes. National models using HYPE model in the 39,653 sub-catch-ments. Take into account most river and lake nutrient processes, and includes lakes, rivers including smaller rivers, reservoirs. Intern sediment load in lakes including where mass balance was supported by monitoring in inlet and outlet.	Yes. Load from Norwegian and Finnish catchments calculated from Corine Land Cover land use data, but with less detailed information on anthropogeny land use sources. Retention also taken into account for point sources and land use sources. Sweden report division of flow and load in Torna Älv between Finland og Sweden Torna Älv is based on monitoring of riverine load and flow, and on monitoring data on point sources in both countries.	Not reported

			Concentration for TN and TP agricultural land calculated by the NLeCC – includes SOILNDB for N and ICECREAMDB for P (using fertilizer, atm. dep., crop yield, catch crops, buffer zones, agricultural practices, weather data, crop rotation, soil type, soil P, soil slope). Specific concentration for land use forest, wetlands, alpine and open land based on representative data based on monitoring campaigns. Leaching for forest, wet lands and mountainous areas is calculated with the HYPE model. Stormwater: runoff coefficients and specific leakage concentrations from statistics and adjusted using weighting by nitrogen deposition rates.			

			<u>Scattered dwellings:</u> Number of populations not connected, load per person, reductions efficiencies of applied techniques and information on treatment techniques. <u>Atm. dep.</u> MATCH model (N) and monitoring (P). <u>Load oriented approach</u> Net load at sea calculated with retention with HYPE model in 39,653sub-catchments. Calculated load at river mouths weighted with total loads from the annual PLC reporting in monitored and unmonitored rivers.			

3.Summary remarks and discussion on the applied methodologies

This chapter includes summary remarks on the reported methodologies and some comments to the applied methodologies including the comparability of the results from the used national methods. Some identified shortages and needs for improvement are indicated in the *paragraphs with italic letters*.

Calculation of flow and loads (rivers, direct point sources)

Two methodologies are mainly applied for rivers load:

- Calculated from daily means of flow and daily concentration (daily concentration applied by interpolation)
- Calculated from mean monthly flow and mean monthly concentration

If countries are monitoring water level continuously (as recommended in the PLC guidelines) and take chemical samples at least monthly use a daily flow and daily concentrations for load calculation should be considered making data more consistent and comparable. Monthly mean methods are overall underestimating loads. When monthly means of flow and more frequent sampling than monthly is available it should be used rather than monthly values.

For wastewater treatment plants and industries, the method(s) of load estimates depends on both the size of these point sources (big sources have a higher sampling frequency) and the traditions in the countries. Some countries use daily mean and daily concentration for load calculation for point sources with at least 12 annual samples, other countries use monthly or even annual mean concentration and flow.

Some countries are sampling point sources bigger than 30 PE, in other countries plants are bigger than 1000 PE before sampling are required. Further, data for some industries are not available in/provide by all countries.

There is a need for further harmonizing load calculation methods for both riverine loads and especially for loads from wastewater treatment plants and industries. At present data from these sources – and particularly from minor sources – are not fully comparable and consistent, and certainly not all discharges are included from all point source in some countries. Further there is uncertainty related to how untreated wastewater in urban areas are quantified and reported

For scattered dwellings some countries apply country a specific loss per PE while other countries considering treatment category for scattered dwelling and use statistics for accounting how many dwellings are included in different categories in the catchments.

The applied methodology is quite unclear or not specified for stormwaters e.g. how the amount of precipitation (and intensity of precipitation) is taken into account and how concentration of chemical compounds have been estimated/assumed. The removal percentages are not specified for many countries, and how it is quantified is often not specified.

There is a need to clarify the used TN and TP per PE for scattered dwelling in the countries, how various treatment (if any) is considered, how number of and treatment level/type for scattered dwellings are quantified, to specify methods used for quantifying inputs from stormwaters, and inform about the completeness of the quantification og stormwaters, include flow quantification. Further it should be harmonised how removal percentages are quantified. These sources (particularly for TP) are of increasing importance and they are the wastewater sources with the highest uncertainty on the quantified inputs. There is a need to further harmonize the definitions, methodologies and the completeness in quantifying these sources.

For marine fish farms consumption of feed (fish production) and food conversion rates are used when available. For freshwater fish farm food consumption (fish production), food conversion rates and any treatment is used (if available), but at least one country use monitoring in inlets and outlets to estimate net loads from fish farms. Further, national/regional statistics might be used.

There is a need for further clarification regarding N and P content in food, food conversion rates, determining losses from fish production within inland water fish farms, how any treatment etc. is taken into account, and if all fish plants are included in the reporting/ assessment. Inputs from aquaculture might be the point source with the most incomparable and inconsistent inputs, and there is a need of further harmonization of TN and TP input quantification methods, and to ensure that all aquaculture activities are included in the assessment, and the necessary data to calculate load from fish farms are available/collected.

For other types of aquaculture there seems to be no reporting.

Losses from *phosphogypsum stacks* should in principle be included in the inputs quantification from monitored areas and the corresponding estimates from unmonitored areas but this is not requested specified from countries. There are also phosphogypsum stacks in the sea leaching e.g. phosphorus, but this source has not been included in PLC-assessments.

More attention is needed to specify losses from phosphogypsum stacks to inland waters, and losses directly into the sea should be quantified as a direct point source and included when quantifying nutrient and hazardous substances inputs.

Inputs from unmonitored areas

Inputs are estimate by overall two methods:

- Area proportion
- Specific modelling

The area proportion methods are divided in two sub-methods:

- Upscaling the monitored part of the catchment to the mouth by simple area proportion
- Using discharge weighted concentration from the monitored part of the river or from neighbouring catchment with corresponding characteristics (as land use, soils types, agricultural practices etc.) to estimate unmonitored part of the rivers and/or unmonitored rivers. Some countries use discharge weighted concentration from only some selected rivers on all unmonitored part of the catchment – others are dividing the catchment area in the country in some regions and sub-regions

Some countries use specific model based on soil type characteristics, land use and some specific agricultural practices parameters, weather parameters, modelled flow, quantified point sources losses or simple modelled coefficients etc. to estimate diffuse and/or total inputs from unmonitored areas.

It is not clear how some countries take into account inputs from points sources in unmonitored areas. Is it correct to assume corresponding proportion of point sources in unmonitored areas as in monitored areas? Do countries have information on point sources in unmonitored areas – then it is only the diffuse part that needs to be monitored/estimated.

When the proportion of unmonitored area are low (e.g. less than 5-10%) by taking into account the point sources in unmonitored areas, using area proportion/discharge weighted concentration from monitored areas should provide comparable results (if the monitoring result are comparable). When the proportion of unmonitored area are higher, it is recommendable to use more extensive modelling and take into account specific characteristics of the unmonitored area. Overall, if information on point sources is available in unmonitored areas (e.g. point sources are actually are monitored/quantified), this information should be used.

For countries/catchments with more than 5-10% unmonitored areas the applied methodology is not fully consistent and comparable between countries.

More detailed information on the applied models by countries are in annex 1.

Source apportionment (load- and source-oriented approach)

Load oriented approach:

- Most countries follow overall the methodology of the PLC guideline estimating anthropogenic diffuse losses as the remaining part of the monitored load after subtracting input from point source, scattered dwellings, storm waters, and natural background losses and by considering retention in inland surface waters
- Most countries consider retention on sources. Some countries are estimating different retention coefficient form different sources, and are also estimating different retention coefficient in monitored and unmonitored areas, and take into account the distance from source emission point
- Some countries don't quantify atmospheric inputs on inland surface waters, and input from scattered dwellings and/or stormwaters

The load-oriented approach accumulates the uncertainty on the anthropogenic diffuse sources. If some of the point sources are not quantified as inputs from scattered dwellings and/or storm waters, then the estimated anthropogenic diffuse losses (which usually is seen as an estimate of the inputs from agricultural sources) will be over-estimated. This is also the case if atmospheric deposition on inland surface water is not quantified. The estimate is also dependent on how natural background losses are estimated e.g. if they are calculated for the entire catchment. The estimated anthropogenic diffuse sources are also depended on how retention is calculated and taken into account.

Further, it is quite obvious that it is important to take into account how inputs from unmonitored areas are quantified and included in the source quantification of the load-oriented approach.

Although the load-oriented approach uses more harmonized methodology than the source-oriented approach, further efforts are needed e.g. on quantifying some of the diffuse sources including natural background, scattered dwellings and stormwaters, atmospheric deposition on inland surface waters, and on how input from unmonitored areas and retention are quantified and considered, to make results more comparable and consistent.

Source oriented approach:

- Many countries use rather comprehensive models to estimate diffuse sources entering into surface waters (EstModel, DK-QNPv2, HYPE, IEEPILLM, MoRE, NLeCC, MATCH, SOIL-N, SWAT, VEMALA (including SYKE-WSFS and ICECREAM) or other national models). Models range from empirical (EstModel) to physio-chemical process-oriented modelling
- Some countries have not fully performed the source-oriented approach

- Some countries models each sources/pathways separately, other countries model mainly diffuse sources aggregated (e.g. not separating inputs from atmospheric deposition on inland surface waters, scattered dwellings and stormwaters from agriculture). Some countries apply the same methodology quantifying sources in monitored and unmonitored areas, other countries have different methods in monitored and unmonitored areas
- The size of modelling units varies, some countries use small units (few square kilometres), estimating both flow and different diffuse source for each unit, while other countries model only for large units and are aggregating several sources
- Retention is generally considered – some countries in each modelling unit and directed to each source/pathway, and other countries apply retention with a more aggregated approach
- Atmospheric deposition on inland surface waters is considered (and modelled/monitored) by many some countries. One country also takes into account atmospheric inputs on the catchment
- Only two countries quantify inputs from agriculture and managed forestry separately
- Some countries use statistics, literature-based values etc. for e.g. estimating losses from scattered dwellings, storm waters, atmospheric deposition on inland surface waters, natural background losses etc.
- Natural background are quantified either based on modelling, monitoring result from catchment will now or low anthropogenic inputs or a combination of these approaches, and the area specific TN and TP natural background losses show big variation between countries
- Some countries use annual actual data (one year), other countries use an average of several (e.g. 5) years. Further some input parameters for the models might be the average for several years (or estimated for large areas), normalized inputs etc.

Many of the challenges described for the load-oriented approach are also valid for the source oriented approach.

Substantially more modelling is involved in the source-oriented approach as compared with the load oriented approach, including the use of either very small or large modelling units. The results should be compared only very carefully between countries and the source data are not very consistent.

There is a need to further discuss where it is relevant to harmonize the methodologies, and the requirements for documenting the applied models, to be able to assess data and facilitate inter-comparison of national source apportionment data. It should be further *discussed if source apportionment (source-oriented approach) could/should be based on average of 3 or 5 years and/or normalized data.*

A pilot study applying some of the country methods on the same catchment to allow for comparing results could facilitate evaluation of comparability and consistency of these methods.

More detailed information on the applied models by countries are in annex 1.

Retention

Several methods or approaches are used:

- Monitoring incoming and outflow in sub-catchments (mass balance approach)
- Models on lakes calculated individually per lake (Behrendt & Opitz (3 countries), MORE, Michaelis-Menten equation, SMED-HYPE, SWAT or national model)
- Some countries use different models for different type of lakes and for retention in rivers
- Standard retention coefficients from literature and comparable lakes and rivers
- Some countries used different models in monitored and unmonitored catchment, and use different retention coefficient for individual sources

For some countries it is not specified whether retention is considered for all lakes, and for several countries it is not describe how and whether retention in rivers is included (or is relevant to consider). There is a need to calculate retention in all inland surface waters.

It should be clarified if some countries are including retention in soils, groundwater etc. in the retention estimates.

It should be discussed if and how retention estimation takes into account the location/distribution of major sources - e.g. if a point discharges in the upper or lower part of a catchment.

There is a need to clarify how retention in connecting with flooding is considered.

It should be clarified how retention is aggregate from small catchments to the catchment to a Baltic Sea sub-basin.

It should be discussed how to consider different retention coefficients for individual sources.

Many countries use rather sophisticated methods for determine retention, but it would be relevant to compare the applied methods if they provide consistent and comparable results (pilot study applying the different methods on the same catchments).

More detailed information on the applied models by countries are in annex 1.

Transboundary inputs

Several methods or approaches are used:

- "Based" on monitoring at the border and take into account retention in the downstream catchment – either by calculation of load at the border, or using flow weighted concentrations
- Based on agreed proportion agreed between two countries e.g. Narva and Oder
- Divide inputs in proportion to division of catchment area
- Modelling approaches
- Disregarding transboundary inputs

Some countries use a specific methods per river.

Some countries have not reported their methodology.

For some transboundary rivers no estimations are made on the shares between countries.

The estimation of transboundary inputs need clearly further work on methodology and cooperation between countries including also countries not being HELCOM Contracting Parties.

It is obvious for some rivers to monitor inputs at the border and estimate the retention in the downstream catchment with agreed method.

Where a river cross the border several times or where the rivers divide into branches, or rivers that are crossing borders of several countries there is a need to agree on a specific methodology including how to estimate retention in each country. Overall, for the big/bigger rivers, sampling at the border is the recommendable method.

For minor rivers it might be possible to divide inputs according to area proportion in the countries if land-use, soil type, hydrology and topography are comparable, and if bigger point sources are taken into account.

Uncertainty on flow, loads, unmonitored and total inputs and on sources

Only three countries have (partly) reported on the uncertainty on flow and load, and total loads. Although in the MAI and NIC assessments an overall estimate has been calculated on total inputs of TN and TP per sub-basin and country per basin. Uncertainty on sources are not provided by any country.

Denmark has developed a methodology for estimating uncertainty on monitored load (per river), monitored loads per catchment, unmonitored loads and total loads. The methodology is described in the PLC guidelines. Germany made expert judge on uncertainties. Latvia provides estimates on the uncertainty on flow measurements, but not on loads from.

In the revised PLC-guidelines there is a methodology included to estimate uncertainties on monitored and unmonitored inputs and total inputs. Further, uncertainty on point sources loads could be estimated by applying this methodology. Uncertainty estimates for sources and how these estimates should be calculated, is closely related to the methodology and model applied quantifying the sources. Further work is needed to allow for quantifying uncertainty and make them comparable between sources and countries, and this should be including in the next revised PLC guidelines.

4. Denmark

By Lars M. Svendsen, Henrik Tornbjerg and Søren Erik Larsen, DCE, Aarhus University, Denmark

Calculation of flow and loads (rivers, direct point sources)

Denmark overall follows common agreed methodologies. Danish rivers are overall quite small or very small and even reporting 178 monitored rivers Denmark only covers about 60 %) of the Danish catchment area to HELCOM convention. It should be remarked that even in unmonitored catchments discharges from point sources >30 PE are monitored.

Denmark has re-reported flow, annual TN and TP inputs for the complete time series (1995 and onwards) also updating some point source data a couple of time – the main reason for the re-reported being changed methods to estimated losses from unmonitored areas and retention calculation, and further for taking into account discontinuity in the precipitation time series from the Danish Meteorological Office (potential underestimation of the precipitation after 2010 with about 8 %) and due to laboratories using wrong methodology resulting in underestimation of organic fraction of particularly nitrogen but also for phosphorus.

The monitoring criteria for point sources have also been unchanged since 1989. The Danish monitoring programme has until recently been focused on nitrogen and phosphorus compounds and organic matter. Since late 1990'ties also some heavy metals and hazardous substances have been monitored on very few, selected rivers and selected major point sources (wastewater treatment plants and industries with separate discharge), but these substances are not monitored every year in these rivers. For some heavy metals and most hazardous substances the main part of analysed concentrations has been under the detection limit and no total loads to coastal waters have been calculated as yet.

Analysis has to be performed on accredited laboratories and only few (1-2) laboratories have been involved for the past 8-10 years. Monitoring is until 2006 performed by the Danish Counties, thereafter by the Ministry of the Environment, and they decide which laboratories they contract to perform chemical analysis.

In Denmark all point sources bigger than 30 PE are monitored even if they are situated in the unmonitored (part of) river catchment area. The frequency and sampling method is given in table 1.

Table 1. Annual sampling frequency (minimum) for wastewater treatment plant outflows.

Plant capacity (PE)	Frequency/yr (min.)	Sampling method
30 ≤ x < 200	2	Random samples [1)]
200 ≤ x < 1,000	4	Time-weighted daily samples [2)]
1,000 ≤ x < 50,000	12	Flow-weighted daily samples
50,000 ≤ x	24	Flow-weighted daily samples

1) Time-weighted samples, random samples or empirical values, and 2) Time-weighted samples or random samples if the necessary facilities for collection of flow-weighted samples are not available. PE: Person equivalent to be equivalent to 21.9 kg organic matter per year measured as biochemical oxygen demand (BI_5), 4.4 kg total-N per year or 1.0 kg total-P per year for some years, but the P-value will be reduced in future.

Measurement of the water volume discharged is in general continual registration of the water volume on the day in question.

Calculation of total discharges follow the PLC guidelines.

Plants with a capacity > 500PE covers 99% of the total wastewater load to wastewater treatment plants.

In Denmark all point sources bigger than 30 PE are monitored even if they are situated in the unmonitored (part of) river catchment area. The frequency and sampling method is given in table 2.

Measurement of the water volume discharged is in general continual registration of the water volume on the day in question.

Calculation of total discharges follow the guidelines.

Many heavy metals and hazardous substances are monitored at selected wastewater treatment plants and separate discharging industrial plants.

Table 2. Discharge classes for industries with separate wastewater discharges indicating the amount of nitrogen (total-N), phosphorus (total-P) and organic matter (BI_5 (modified) and COD) discharged together with the sampling frequency.

Discharge class	Discharge (tonnes/yr)				Frequency/yr
	BOD_5 (mod.)	**COD**	**Total-N**	**Total-P**	
I	0.6 < x < 4.3	1.6 < x < 10.8	0.13 < x < 0.9	0.005 < x < 0.3	2 samples
II	4.3 < x < 21.6	10.8 < x < 54	0.9 < x < 4.4	0.3 < x < 1.5	4 samples
III	21.6 < x < 108	54 < x < 270	4.4 < x < 22	1.5 < x < 7.5	12 samples
IV	x > 108	x > 270	x > 22	x > 7.5	12 samples

Storm water and scattered dwelling

TN and TP loads are based on statistical information. For storm waters it used statistics on outlets with rainwater from fortified areas and from overflows with sewage and rainwater. Precipitation is used in the calculation of TN and TP losses.

For scattered dwellings for each household information of type of wastewater cleaning system get a theoretical degree of purification, which is combined with number of inhabitants in different types of households and excretion of TN and TP per person (PE) (annually 4.4 kg TN, 1 kg TP (this number is under revision and will be lowered markedly) and 21.9 kg BI_5). Based on a study from the Technical University of Denmark (DTU) the TP amount in wastewater per person has been revised to the values shown in table 3 (Arildsen & Vezzaro (2019) https://orbit.dtu.dk/files/166318737/MST_rapport_ny_P_PE_jan2019.pdf [2]

[2] Arildsen, A. L., & Vezzaro, L. (2019). Revurdering af person ækvivalent for fosfor - Opgørelse af fosforindholdet i dansk husholdningsspildevand i årene fra 1990 til 2017 (Re-evaluation of a phosphorus person eqvivalent – Compolation of phosphorus content en wastewater from households during 1990-2017 (in Danish)). Danmarks Tekniske Universitet (DTU) 64 p.

Table 3. TP excretion per person (PE).

Year	TP (kg PE^{-1} $year^{-1}$)
Up to 1990	1,3
1991-2007	1,0
2008	0,93
2009	0,86
2010	0,79
2011-	0,72

Rivers

The annual sampling frequency at each river monitoring site is generally 12-18. Stage (water level) is recorded continuously (either sampled every 10 minutes or averaged over 10 minutes) at all river monitoring stations. Discharge (cross section of river monitored in several depths in several depth profiles) is measured at least 12 times per year, and continuously run off is calculated using a well-established stage-discharge relationship which take into account any impounding effects on stage caused by aquatic plants. Transport at each river monitoring station is calculated by multiplying daily discharge with daily concentration, the latter estimated by linear interpolation of measured values.

Inputs from unmonitored areas

Denmark has developed a new standardised method for estimating diffuse losses and loads from unmonitored areas. The new models estimate run off, diffuse losses and loads of nitrogen and phosphorus respectively. To these loads, the load from point sources in unmonitored areas is added. As explain earlier all discharges from point sources >30 PE are monitored, and discharges from scattered dwelling are based on information on number of scattered dwellings and which kind of purification the individual scattered dwellings have. Discharges from storm water overflow are estimated based on precipitation and e.g. the fortified are connect to e.g. an overflow pipe.

Denmark has developed a new standardized method for estimating diffuse losses and loads from unmonitored areas based on the original model described in Windolf et al. (2011). The new models estimate run off, diffuse losses and loads of nitrogen and phosphorus respectively. To these loads, the load from point sources in unmonitored areas is added. As explain earlier all discharges from point sources >30 PE are monitored, and discharges from scattered dwelling are based on information on number of scattered dwellings and which kind of purification the individual scattered dwellings have. Discharges from storm water overflow are estimated based on precipitation and e.g. the fortified are connect to e.g. an overflow pipe.

Shortly described run-off is calculated for 500 * 500 m grids with use of Danish groundwater model from Geologic Survey of Greenland and Denmark (the so called "DKmodel_Qflow", Stisen et al. (2019)) but adjusted and calibrated by DCE with discharge measurements in several hundreds of rivers to fit with monitored run off in rivers. The run-off is aggregated to monthly values and for 3351 ID15-catchments with a mean area of 13 km^2.

Further two models calculate nitrogen and phosphorus monthly flow-weighted concentrations, respectively for different unmonitored catchments. Calculations of diffuse losses are done on a monthly basis for ID15-catchments. These flow-weighted concentrations are multiplied by the calculated flow from 500*500 m grid to calculate diffuse losses including natural background losses. Relevant point source discharges are added.

Thereafter retention of nitrogen and phosphorus in rivers, lakes and wetlands are deducted from the calculated diffuse losses to get estimate of the riverine loads in unmonitored areas. Retention is estimated using lake retention models, denitrification and net retention of phosphorus in rivers and wetlands (and due to flooding) and taking into account lake, river and wetland characteristics.

The nitrogen model (DK-QNv2-model) is based on data from 84 monitored agricultural catchments without big lakes and the monthly flow weighted nitrogen concentrations are calculated for ID15 polygons as a function of:

- soil type (% sandy soils) (based on map scale 1:50000)
- percentages of cultivation (from centralized detailed database)
- degree of drainage (based on 205*205 m rastermap)
- monthly precipitation (daily data from 10*10 km grids)
- monthly average air temperature (daily from 20*20 km grid)
- calculated nitrogen surplus based on national data (from Blicher-Mathiesen et al., 2015)

The statistical phosphorus model (DK-QPv2)-model is based on data from 207 monitored agricultural catchments without big lakes (Larsen et al., 2022) and the yearly flow weighted phosphorus concentrations are calculated for ID15 polygons as a function of:

- degree of drainage (based in 30x30 m rastermap)
- percentage of paved area

- percentage of cultivated area
- bank erosion
- yearly precipitation (daily data from 10*10 km grids)
- yearly precipitation deviation from mean yearly precipitation 1991-2020
- soil type (% sandy soil)
- percentage clay soil in 1-2 m depth
- number of frost days
- centroid coordinates of catchment

The phosphorus model for the yearly flow weighted phosphorus concentrations is a machine learning model of the type "eXtreme Gradient Boosted Trees Regressor with early stopping"

The nitrogen and phosphorus models have a regional bias by overestimating nitrogen concentrations in the Western parts of Denmark, and with a tendency for underestimation in the eastern part of the country. This bias is perceived as a general model bias. Therefore, a bias correction of individual monthly inputs from unmonitored areas is carried out in the same geographical regions as used in Thodsen et al. (2019a). However, an additional region covering Himmerland has been added, where is it known that the temporal development in the measured loads, does not coincide with the modelled loads. The bias correction method is described in Thodsen et al. (2019b).

The total run off and load of nitrogen and phosphorus via rivers from Denmark since 1995 have therefore been recalculated with the above-mentioned new models, and that is the reason for the re-reporting the complete flow and TN and TP loads time series for the PLC-6 assessment. In average for Denmark, the new models result in lowering annual nitrogen loads via rivers with 6-7 %, but on an annual basis with from approx. 15 % lower up to the same loads as compared with former reporting. Concerning phosphorus loads via rivers in average the revised load are 6 % higher, but on an annual basis loads is between 10 % lower to + 15 % higher compared with former reporting. In some catchments there are some major differences compared with former results, and DCE are investigating the reasons behind.

For further details see:

Blicher-Mathiesen, G., Rasmussen, A., Andersen, H.E., Timmermann, A., Jensen, P.G., Hansen, B. & Thorling, L., 2015, Monitored agricultural catchments 2013: NOVANA (in Danish). Aarhus University, DCE – Danish Centre for Environment and Energy, 154 p. - Scientific report from DCE - Danish Centre for Environment and Energy no. 120.

Larsen, S.E., Kjeldgaard, A., Windolf, J., Tornbjerg, H. & Kronvang, B., 2022: New phosphorus model estimating annual flow-weighted concentrations of phosphorus from diffuse sources in ID-15 catchments (in Danish). Aarhus University, DCE – Danish Centre for Environment and Energy, 80 p. - Technical report no. 246. http://dce2.au.dk/pub/TR246.pdf

Stisen, S., Ondracek, M., Troldborg, L. Schneider, R.J. M. and van Til, M.J., 2019: National Water Resource Model: Setting up and calibration of the DK-model 2019. Geologic Survey of Denmark and Greenland, 271 p.

Thodsen, H., Tornbjerg, H., Troldborg, L., Windolf, J., Ovesen, N.B., Kjeldgård, A. & Højberg, A.L. 2019a: Development of the flow part of the DK-QNP model for quantifying flow, nitrogen and phosphorus inputs to the sea (In Danish). Aarhus University, DCE – Danish Centre for Environment and Energy, 20 p. - Technical report no. 145.

http://dce2.au.dk/pub/TR145.pdf

Thodsen, H., Tornbjerg, H., Rasmussen, J.J., Bøgestrand, J., Larsen, S.E., Ovesen, N.B., Blicher-Mathiesen, G., Kjeldgaard, A. & Windolf, J., 2019b: Rivers 2018. NOVANA (in Danish). Aarhus University, DCE – Danish Centre for Environment and Energy i, 70 p. – Scientific report no. 353.

http://dce2.au.dk/pub/SR353.pdf

Windolf, J., Thodsen, H., Troldborg, L., Larsen, S.E., Bøgestrand, J., Ovesen, B. & Kronvang, B., 2011: A distributed modelling system for simulation of monthly runoff and nitrogen sources, loads and sinks for ungauged catchments in Denmark. Journal of Environmental Monitoring 13: 2645-2658.

Source apportionment (load- and source-oriented approach)

Denmark follows the PLC guidelines for the load-and source-oriented approach.

Atmospheric inputs is calculated on inland surface waters based on national monitoring program and dry and wet deposition of nitrogen which then are modelled to and annual deposition rate. For phosphorus deposition Denmark uses 0.04 kg P/ha surface inland waters.

Retention

Retention is modelled for larger lakes, small ponds and lakes, streams and restored wetlands and also in unmonitored areas.

Larger lakes:

All larger lakes for which both an inlet and an outlet has been identified are in this context defined as larger lakes. For each lake, the external annual nitrogen load has been estimated using a distributed model (Windolf et. Al, 2011) and the annual nitrogen-retention is calculated using a N-retention model. The lake nitrogen retention (N_{ret}) model includes water residence time (T) and average lake depth (Z):

$$N_{ret} = (k * T^{a} * Z^{-b}) -1 \quad (\text{for } N_{ret} \leq 90) \qquad (1)$$

Where N is in percentages, T in years and Z in meter.

The model is based on monitoring data on annual inflow and outflow of water and nitrogen from 21 lakes over a 15-year period and using this data equation 1 is calibrate as:

$$N_{ret} = (78{,}52 * T^{0.431} * Z^{-0{,}078}) -1 \quad \text{for } N_{ret} \leq 90)$$

If N_{ret} is calculated higher than 90% it is set to 90%.

Retention of phosphorus have been calculated for 600 in Danish context larger lakes. Based on an empirical relationship between phosphorus retention in 21 lakes (the same lakes as used for nitrogen for equation 1) from mass-balance calculation and the flow from these lakes an annual retention rate (kg P per hectare lakes surface) has been calculate for 600 lakes (Tornbjerg & Thodsen, 2018). The result is depending on the proportion of bigger lakes areas in the individual catchment, and the resulting phosphorus retention expressed as kg P per hectare catchment areas show high variability:

71 Monitored catchments: average 0.069 kg P/ha with 5% and 95% percentile 0.001 and 0.46 kg P/ha, respectively

743 unmonitored catchments: average 0.033 kg P/ha with 5% and 95% percentile 0.002 and 0.11 kg P/ha,

Based on the retention rates above phosphorus retention constitutes 7-10% of the annual total phosphorus inputs from Denmark to the sea.

Small ponds and lakes:

The Danish landscape is dotted with more than 100.000 small ponds and lakes. With the aim to identify the number of minor lakes having a significant potential for N retention the following criteria were established

- Each lake should at least have an identifiable stream outlet and/or "have contact" with at least two ditches. A total of 5.930 smaller lakes were identified to meet the criteria.
- No topographic catchment areas are available for these lakes. Hence the calculation of nitrogen retention is based on assigned lakes area specific mean annual retention rates between 60 and 400 kg N ha^{-1} per year.
- The ranges of retention rates aim to reflect the differences between lakes located in areas with varying farming intensities and varying soil characteristics.
- Inter-annual variation in the area-specific N retention rates is calculated based on the assumption that it follows the relative inter-annual variation in nitrogen retention in determined from mass balances in 16 Danish lakes.

Streams

The calculation of nitrogen retention in streams are based on 41 referenced studies of nitrate denitrification in streams and rivers in different parts of the world reviewed by Kronvang et al. These showed that annual average nitrate denitrification rates were higher in stream channels wider than 2 m than in stream channels less than 2 m wide. The total length of the different width classes was extracted from a national dataset. Inter-annual variation in N retention rates in streams is presumed to parallel the relative inter-annual nitrogen retention in 16 larger Danish lakes.

Retention of phosphorus is not calculated or estimated for rivers.

Restored wetlands

Experience from Denmark following the effect of restored riparian wetlands shows a net removal of nitrogen amounting up to 190 kg N per hectare restored wetland per year. Data on the location of restored wetlands in Denmark since 1998 are recorded in GIS and information on the annual areas of restored wetlands is extracted and stores in GIS. Inter-annual variation in the nitrogen retention rate is assumed to parallel the inter-annual variation in nitrogen retention in 16 larger Danish lakes.

Retention of phosphorus is not calculated or estimated for restored wetlands.

References

Højbjerg, A., Thodsen, H., Børgesen, C.D., Tornbjerg, H., Nordstrøm, B.O., Troldborg, L., Hoffmann, C.C., Kjeldgaard, A., Holm, H., Audet, J., Ellermann, T., Christensen, J.H., Bach, E.O., Pedersen, B.F. (2020) National nitrogen model version 2020. Methodology report (in Danish). De Nationale Geologiske Undersøgelser for Danmark og Grønland. GEUS Specialrapport, 104 pp.

Tornbjerg, H., Thodsen, H. (2018). Information on phosphorus retention factors in monitored and unmonitored catchments (in Danish). Technical report from DCE – Danish Centre for Environment and Energy – 5 p.

Windolf, J., Thodsen, H., Troldborg, L., Bøgestrand, J., Ovesen, N. B., (2011): Journal of Environmental Monitoring, vol 13, 2011, p. 2645-2658.

Natural background losses.

The natural background losses from Denmark (OSPAR and HELCOM catchment areas) is based on monitoring in seven minor natural catchments with very low anthropogenic inputs besides atmospheric inputs - has been calculated from the maps below with flow-weighted concentrations of Total-N and Total-P taking into soil types and specific runoff in each grid (nitrogen) and geo-region (phosphorus).

Nitrogen natural background losses are calculated for nearly 2.250 5*5 km grid and for 9 geo-regions (see maps below).

The median flow-weighted nitrogen background concentration is 1.2 mg/l and the range (minimum to maximum) for the grids is from 0.61 to 1.48 mg/l. The corresponding values for phosphorus are median 0.066 mg/l and the range from 0.021 til 0.089 mg/l.

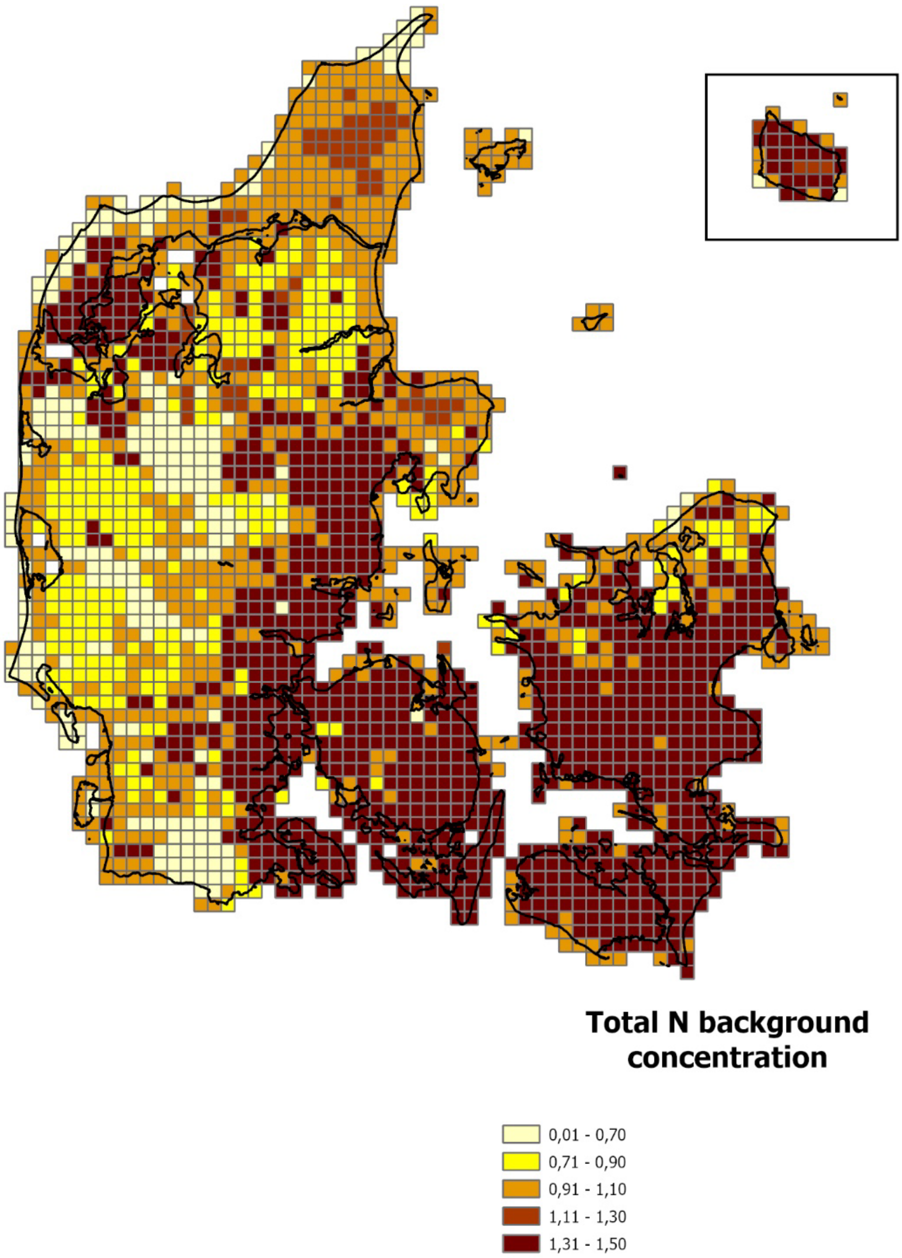

Figure 1. Natural total-nitrogen background flow-weighted concentration in Denmark for approx. 2.250 5*5 km grids.

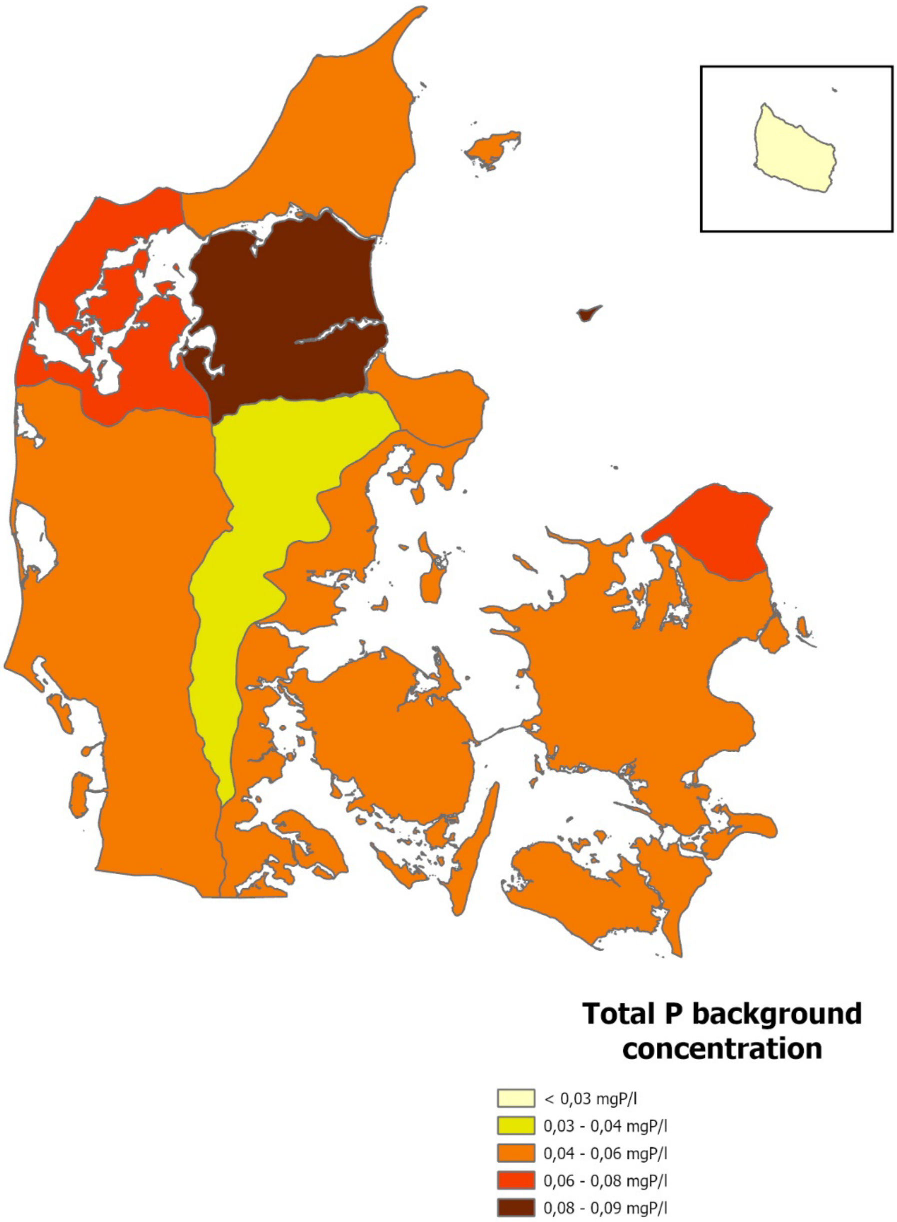

Figure 2. Natural total-phosphorous background flow-weighted concentration in Denmark divided in nine geo-regions.

Transboundary inputs

Denmark has no transboundary rivers to take into account.

Uncertainty on flow, loads, unmonitored and total inputs and on sources

Denmark have been working with estimating uncertainty on inputs using the method below. The example is for total nitrogen. Uncertainty estimates Is described for monitored, and unmonitored areas separately, and for total inputs to the sea.

Monitored area:

The calculation of the uncertainty is done by using the statistical principle “Propagation of errors”. This principle can be explained as:

Let *X* be the sum of *n* stochastically independent measured loads

$$X = \sum_{i=1}^{n} X_i. \qquad (3.1)$$

The variance of *X* can be calculated as

$$\sigma_X^2 = Var(X) = \sum_{i=1}^{n} \sigma_{X_i}^2. \qquad (3.2)$$

The standard deviation is then calculated as

$$\sigma_X = \sqrt{\sum_{i=1}^{n} \sigma_{X_i}^2}. \qquad 3.3)$$

And the relative standard deviation (denoted the precision) is calculated as

$$100 \cdot \frac{\sigma_X}{X} = \frac{100}{\sum_{i=1}^{n} X_i} \sqrt{\sum_{i=1}^{n} \sigma_{X_i}^2}. \qquad (3.4)$$

The calculation of the total inputs from the monitored areas constitute of measurements from 169 stations in streams. These stations cover approximately 55% of the total Danish catchment area. Bias and precision can then be calculated as

$$bias\ (\%) = \frac{100}{\sum_{i=1}^{169} X_i} \sum_{i=1}^{169} bias_i \cdot X_i, \qquad (3.5)$$

$$precision\ (\%) = \frac{100}{\sum_{i=1}^{169} X_i} \sqrt{\sum_{i=1}^{169} (precision_i \cdot X_i)^2}. \qquad (3.6)$$

The total uncertainty can then be calculated as

$$uncertainty\ (\%) = \frac{100}{\sum_{i=1}^{169} X_i} \sqrt{\sum_{i=1}^{169} (bias_i \cdot X_i)^2 + (precision_i \cdot X_i)^2}\ . \qquad (3.7)$$

The total input to the Danish marine environment is a sum of two components. One component is from the monitored catchment area and the other is from the unmonitored area. The inputs from the unmeasured area is estimated by using a model. A Monte Carlo study (Kronvang & Bruhn, 1996) based on daily samples has shown that for Danish streams categorized by their catchment area, the following values for bias and precision are valid for TN load calculated using the linear interpolation method:

0-50 km^2:	Bias: -1% to -3%;	Precision: 1-3%
50-200 km^2:	Bias: -0.7% to -3%;	Precision: 1-3%
>200 km^2:	Bias: -1% to -4%;	Precision: 2-5%

These number are valid for the yearly load from one stream station and include the uncertainty of laboratory analysis, yearly variation of concentrations and stream discharge and uncertainty from the method for calculating yearly load (by linear interpolation). The uncertainty from the measurement of the concentration in the stream (placement of the sampling site horizontal and vertical in the stream) is not included and therefore 2% is added to the precision in the 3 categories.

Using the formulae (3.5-3.7), it can be calculated that the total bias is -1% to –3%, the total precision is 0.7% to 1.2% and the total uncertainty is 0.7% to 1.3%. For an average stream station the bias is -1% to -3%, the precision is 3% to 5% and the uncertainty is 3.2% to 5.8%.

The TN input from the unmonitored areas is based on model estimates for 1286 very small catchments covering the rest of the Danish area (45%). The year load from each small catchment is calculated using the formula

$$L = Ndiffuse_{model} + R_{lake} + R_{stream} + N_{waste} - R_{total}, \qquad (3.8)$$

$Ndiffuse_{model}$ = the estimated nitrogen inputs from the model

R_{lake}= Estimated nitrogen retention in lakes

R_{stream} = Estimates nitrogen retention in streams

N_{waste} = Nitrogen inputs from wastewater

R_{total} = Total nitrogen retention.

In table 3.2 are shown bias and precision for the components in formula (3.11 based on both numerical calculations, the study by Kronvang & Bruhn (1996) and estimates.

Table 3. Bias and precision for nitrogen inputs in formula (3.11) based on both numerical calculations, estimates and Kronvang and Bruhn (1996).

Components	Bias (%)	Precision (%)
Model	15 to 20	12 to 15
Retention lake	-5 to 5	40
Retention stream	-5 to 10	40
Retention total	-5	40
Point source: industry	-1 to -3	1 to 10
Point source: waste water	-1 to -3	1 to 10
Point source: fishfarms	-1 to -3	1 to 20
Point source: rain water	-5	40

Using the formulae (3.5) to (3.7) and the bias and precision indicated in table 3.2 the total bias for the unmonitored area is calculated to 20% to 28%, the total precision is 0.8% to 2.0% and the total uncertainty is 1.2% to 2.2%. For an average small unmonitored catchment the bias is 27%, precision 15% to 20% and the uncertainty 31% to 34%.

For the total Danish catchment area, combing the calculated bias, precision and uncertainty for both the monitored and unmonitored areas and using special versions of formulae (3.7) to (3.9), we get a total bias of 7.4% to 12.8%, a total precision of 0.5% to 1.1% and a total uncertainty of 7.4% to 12.8% on TN inputs.

With respect to total phosphorus (TP), calculations show that for the measured area the bias is -6 to -3%, the precision is 1 – 2% and the uncertainty is then 1 – 2.5%. For the unmeasured area the bias is between -5 and 30%, the precision is 1 – 3% and the uncertainty is 1 – 4%. These calculations are based on the following values of bias and precision from Kronvang and Bruhn (1996) for TP load (using linear interpolation method):

0-50 km^2:	Bias: -16% to -27%;	Precision: 18-37%
50-200 km^2:	Bias: -2% to -5%;	Precision: 9-13%
>200 km^2:	Bias: -2% to -4%;	Precision: 3-8%

5. Estonia

By Kristi Uudeberg, Estonian Environment Agency, (e-mail: Kristi.Uudeberg@envir.ee)

Calculation of flow and loads (rivers, direct point sources)

The calculations were carried out according to HELCOM PLC-Water Guidelines 2022. The annual load for every monitored river was calculated for the location of the chemical monitoring station. The load from the unmonitored part of the river catchment area was estimated as a part of the unmonitored areas.

A total of 15 monitored rivers were reported to HELCOM. Among these rivers, the Pärnu River is a transboundary river and the Narva River is a border river. All our monitored rivers have both hydrological and chemical monitoring stations; however, in some cases, these stations are not located in the same place. Monitored and unmonitored areas may be different for different parameters depending on the monitoring program.

Rivers

At hydrological monitoring stations, the river flow is measured daily. Concentrations are measured at chemical monitoring stations 4–12 times per year based on the schedule of the monitoring program. The data is available through national monitoring databases. The daily concentrations are estimated by linear interpolation of measured values. The annual input load is estimated as the sum of the daily concentration multiplied by the daily river flow. If the river flow and concentrations are not measured in the same locations, that means the river's hydrological and chemical monitoring stations are in different locations, then the river flow at the chemical station is calculated as the catchment area covered by the chemical station multiplied the river specific flow at the hydrological monitoring station.

Direct point sources

From 2021, Estonia changed the threshold for the size of industrial or municipal point sources which will be reported. Before 2021 it was 2000 PE and now it is 50 PE. The annual input loads from direct industrial or municipal point sources are calculated using the quarterly reports forwarded to The Estonian Environment Agency. Every water consumer with water use permission must provide these reports. Reports contain quarterly average concentrations and quarterly total flow. The annual input load from the point source is calculated as the sum of the quarterly average concentration for the period multiplied by the wastewater volume for the period. The annual input load from direct aquaculture is usually calculated and reported by the owner.

Inputs from unmonitored areas

Flow and load from unmonitored areas were estimated with monitoring-based estimates of the Estonian estimation model (EstModel). Estimations are based on measurements in monitoring stations and spatial information. In addition to the previously described 15 monitored river monitoring stations, there are other national monitoring stations included to support the estimations of the load and flow from the unmonitored area.

Estonia is divided into three river basin districts and eight sub-units (Figure 1). The average specific runoff is calculated for every sub-unit using that sub-unit station's measurements. The annual input load from the unmonitored area is calculated as the sum of the average specific runoff of the sub-unit multiplied by the sub-unit unmonitored area.

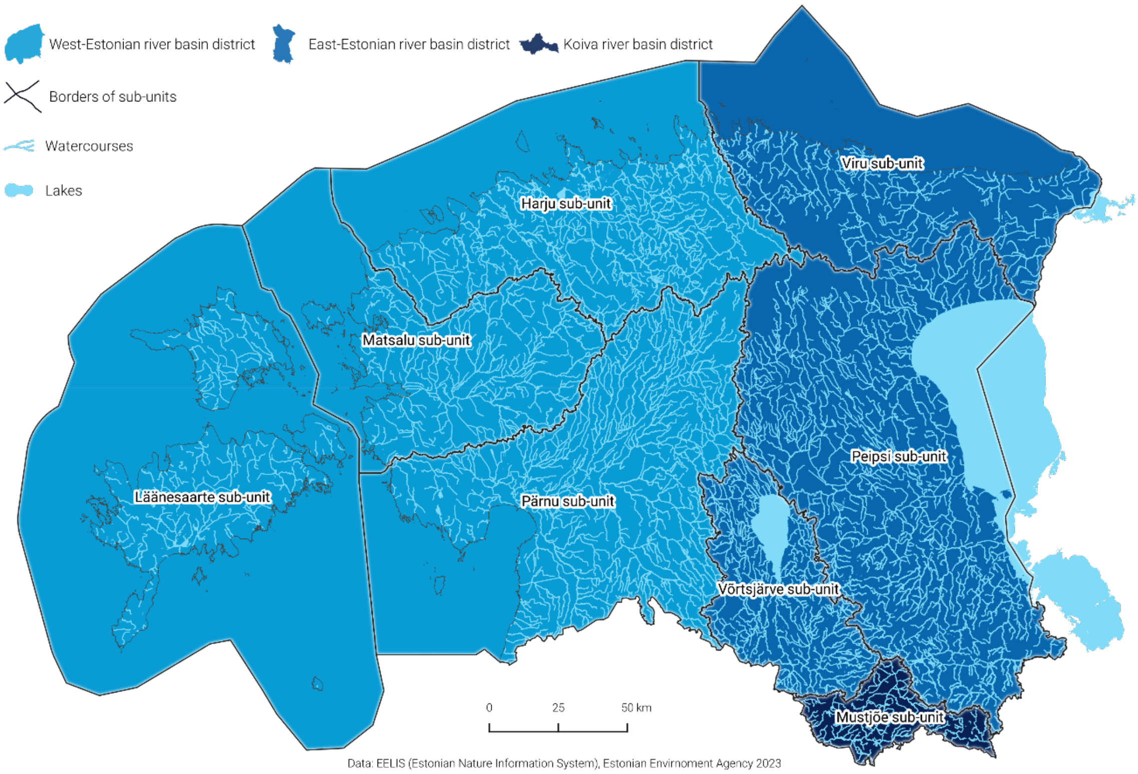

Figure 1. Estonian river basin districts and sub-units.

Source apportionment (load and source-oriented approach)

Source oriented approach

For the compilation of the periodic report, source-based estimations of EstModel were used. This is a simple coefficient-based model to estimate annual nitrogen and phosphorus transport in catchment areas. Estimates are based on subcatchment areas and land cover classes and can distinguish natural, anthropogenic and atmospheric loads. Subcatchments are based on Estonia's national chemical monitoring station network and river basin districts. Estonia is divided into 66 subcatchments. In each subcatchment, the loads from different land cover classes (arable land, forest, grassland, pasture, peatland, urban area, water surface and wetland) are estimated separately.

Natural background losses are calculated based on natural concentrations. The natural concentrations in calculations are 1.21 mg l^{-1} for total nitrogen and 0.04 mg l^{-1} for total phosphorus. Natural concentrations of each subcatchment may vary slightly depending on soil content and LS-factor in the subcatchment.

Atmospheric load onto the water surface was calculated by multiplying subcatchment specific deposition with the area of inland water surface in the subcatchment. Subcatchment specific deposition was found based on 15 phosphorus and 8 nitrogen precipitation monitoring station data in Estonia.

Load from scattered population is considered as an anthropogenic diffuse source and it is calculated as the scattered population, as population equivalents multiplied by the population equivalent value (12 $g \cdot d^{-1}$ for nitrogen and 1.5 $g \cdot d^{-1}$ for phosphorus). In the model, a retention coefficient 0.95 is used for estimating the scattered population load.

Load from stormwater and bypasses is considered as an anthropogenic diffuse source; however, the reported load from stormwater and bypasses is estimated based on point sources. Data is reported to The Estonian Environment Agency.

Load from managed land is considered as an anthropogenic diffuse source. Estimations depend on land use intensity, area covered by drainage systems, use of fertilizers, soil content, and LS-factor.

Load-oriented approach

Load-oriented estimates are calculated from source-oriented estimates by subtracting total retention. Total retention includes point source retention and diffuse source retention. Load-oriented estimates at the chemical monitoring station are adjusted against the annual monitored river load. All load sources (except point sources, atmospheric and scattered dwellings loads) are adjusted according to the weight.

Load-oriented estimates from HELCOM subcatchment reported in the periodic report are estimated to the sea. Therefore, they include additional retention from unmonitored parts of the rivers and differ from loads reported in the annual report.

Retention

The EstModel only takes into consideration the retention from the surface waters of the catchment area. Retention in surface waters indicates how much of the load entered into waterbodies remains in the waterbodies of the catchment area or is released into the atmosphere. Therefore, it enables to estimate how much of the load entered into surface waters leaves from the calculation area. The value of the retention coefficient is between 0 and 1. To find the values of the retention coefficient, the approach based on the Michaelis-Menten equation (Michaelis & Menten, 1913) to estimate the speed of biological processes was used in the EstModel.

$$R^{N,P} = R_{max}^{N,P} \frac{t}{t_{half}^{N,P} + t}$$

where $R^{N,P}$ is the retention coefficient of nitrogen or phosphorus (0–1), $R_{max}^{N,P}$ is the maximum retention coefficient of nitrogen or phosphorus (0–1), t is the retention time and $t_{half}^{N,P}$ is the retention half-time.

Diffuse load retention

To calculate diffuse load retention, the EstModel uses a method, where the value of the retention coefficient of the surface water is related to the estimated residence time of the nutrients in the waterbody. Considering that residence time is the inverse value of the rate of water exchange which depends on the amount of water led off from the subcatchment and the total volume of the waterbodies in the subcatchment, the t was calculated as

$$t = \frac{S_{water}^{lake} \cdot H^{lake} + S_{water}^{stream} \cdot H^{stream}}{Q \cdot 86400}$$

where t is the time water is in the waterbodies (d), Q is the average annual flow ($m^3 \cdot s^{-1}$), S_{water}^{lake} is the total surface area of the stagnant waterbodies (m^2), H^{lake} is the average depth of the stagnant waterbodies (m), S_{water}^{stream} is the total surface area of the watercourses (m^2), H^{stream} is the average depth of the watercourses (m), and 86400 represents a number of seconds in a day.

Point load retention

The retention coefficient of point load is parameter-based (N, P) and point source-based (the retention of each point source is calculated separately) and the calculations consider what type of waterbodies load passes through.

$$R^{N,P} = R_{stream}^{N,P} \frac{D_{stream}}{D_{total}} + R_{lake}^{N,P} \frac{D_{lake}}{D_{total}}$$

where $R^{N,P}$ is the retention coefficient of nitrogen or phosphorus (0–1), $R_{stream}^{N,P}$ is the retention coefficient of nitrogen or phosphorus (0–1) in watercourses, $R_{lake}^{N,P}$ is the retention coefficient of nitrogen or phosphorus (0–1) in stagnant waterbodies, D_{total} is the total distance between point source and the monitoring station (m), D_{stream} is the distance in streams between point source and the monitoring station (m), D_{lake} is the distance in stagnant waterbodies between point source and the monitoring station (m). The retention coefficient in watercourses is calculated using the retention coefficient formula, where retention time is found based on the distance and flow rate of the river. The retention coefficients in stagnant waterbodies are constant based on literature.

The total retention load is the sum of the retention load for each source and the load decrease due to retention is calculated as

$$L\_ret^{N,P} = L^{N,P} \cdot R^{N,P}$$

where $L\_ret^{N,P}$ is the load of nitrogen or phosphorus decrease due to retention, $L^{N,P}$ is the input load of nitrogen or phosphorus, and $R^{N,P}$ is the retention coefficient of nitrogen or phosphorus.

Transboundary and border river inputs

The Narva River is an Estonian and Russian common border river. The total catchment area is 57712 km^2, of which 30 % is the Estonia part. It is agreed the Estonian part is 1/3 of the total load. Unfortunately, since 2015 the hydrological measurements have been stopped (Russian authorities do not give permission to measure the flow in the Narva River). The load is calculated based on the estimated flow.

The Pärnu River is an Estonian and Latvian transboundary river. The river's total catchment area is 6714.2 km^2 of which 18.106 km^2 is our transboundary area. The load of nutrients from Estonia is a proportion of the division of the catchment area.

Uncertainty on flow, loads, unmonitored areas and total inputs and on sources

Uncertainties are not estimated.

References

HELCOM Guidelines for the annual and periodical compilation and reporting of waterborne pollution inputs to the Baltic Sea (PLC-Water). HELCOM (2022).

EstModel, https://estmodel.app/en/

Michaelis, L. and Menten, M. L. (1913): Die Kinetik der Invertinwirkung. Biochemische Zeitschrift, Vol. 49, pp. 333-369.

6. Finland

By Antti Räike, Finnish Environment Institute (SYKE)

Calculation of flow and loads

Riverine discharges

Altogether 29 monitored rivers were included in the PLC-8 work. These monitored rivers comprise about 90% of the Finnish Baltic Sea catchment area. Water flow was measured continuously in each river and water quality samples were taken flow proportionally, usually 12 to 20 times per year. Load from unmonitored areas was estimated by a Finnish watershed model (WSFS-VEMALA), which models, beside hydrology, also nutrient loads on the basis of e.g. land use, catchment properties, and monitoring data (Huttunen et al. 2016). The annual river discharges were based on daily flow values and monitored concentration were interpolated to daily values by linear interpolation.

Estimation of loading

Point source loads

Nutrient load estimation from municipalities and industrial plants were based on regular measurements made according to the guidelines given by the Finnish environmental authorities. In some cases, it is impossible to separate municipal and industrial discharges, because especially wastewaters of food production plants are usually treated in municipal wastewater treatment plants. Nutrient load estimation for fish farms was based on production statistics, amount of feed and nutrient content of the feed, using the equations in the PLC-8 Guidelines.

Source apportionment

For source apportionment the WSFS-VEMALA-model was used, which combines all available information: measured point sources, hydro-meteorological data, water quality data, and modelled diffuse loads and nutrient retention estimates (Huttunen et al. 2016).

Diffuse load

Small drainage basins and small experimental areas were used in the estimations of diffuse source loading. The network of drainage basins for water quality monitoring consists altogether of 45 basins with different type of land use in different parts of the country. Water flow was measured continuously, and water quality samples were taken flow proportionally 35-55 times per year.

Estimation of the losses of phosphorus and nitrogen from agricultural land to surface waters in Finland is based on the monitoring of N and P fluxes from 11 small agricultural drainage basins and from four agriculturally loaded river basins in south and southwestern Finland (Rekolainen et al. 1995, Vuorenmaa et al. 2001). The size of the small basins vary from 0.12 to 15 km^2, and the river basins from 870 km^2 to 1300 km^2. The agricultural land use of the basins varied from 23 to 100%. The monitoring schemes were based on continuous water flow measurement and flow weighted water quality sampling. Using this data, annual N and P flux estimates were calculated, by subtracting possible point-source loads and estimated losses from forested areas and the natural background. The up-scaling of the losses of phosphorus to cover whole Finnish arable land area is based on the ICECREAM model, which takes into account the topography, the structure of soil and agricultural production in different river basins (Tattari et al. 2001). The hydrology of the original model has been modified for Finnish conditions. The most remarkable change is in the model the inclusion of snow accumulation, snow melt and soil frost processes. For nitrogen SOILN-N model was used (Johnsson et al. 1987).

The effects of forestry activities (ditching, clear-cut felling, ploughing, hummocking, fertilization etc.) were evaluated on the basis 23 small forested drainage basins. The specific yearly net load from forestry activities was approximated using leaching coefficients obtained from the Finnish forestry monitoring network.

Nutrient inputs from scattered dwellings were estimated on the basis of estimated annual wastewater production per person and the level of equipment in handling of lavatory and sanitary wastes (table 1). Per capita load estimates were 50 g/d BOD, 14 g/d NTOT and 2.2 g/d PTOT.

Atmospheric deposition on lake surfaces was gained by multiplying specific deposition by the surface area of the lakes. Deposition was measured on 13 stations located in the river catchment areas. Nutrient concentrations were analysed from the integrated monthly samples of rain.

The estimation of natural leaching was based on coefficients obtained from the monitoring programmes of small drainage basins and are variable in different parts of the country (table 2).

Table 2. Average natural leaching in different parts of Finland.

	kg P km^{-2} a^{-1}	kg N km^{-2} a^{-1}
Southern Finland	6	200
Central Finland	5	120
Northern Finland	5	80
Northern Lapland	2	50

Calculation of retention

Estimation of retention is based on the WSFS-VEMALA-model taking into account all load sources (both point and diffuse). Retention of nutrients in freshwaters is in Finland mainly connected to chemical, physical and biological processes taking place in lakes. Unmonitored river catchments and coastal areas in Finland have only very limited number of lakes, and thus retention in these areas is negligible.

Tranboundary inputs

The estimation of transboundary inputs from Finland to Russia is based on monitored inputs of the River Vuoksi. Monitoring of the border River Torne between Finland and Sweden is carried out in both countries. The final input is an average of the loads reported by the two countries. Source apportionment is done by Sweden.

Uncertainty on flow, loads, unmonitored areas and total inputs and on sources

Uncertainty is not estimated.

References

Huttunen, I., Huttunen, M., Piirainen, V., Korppoo, M., Lepistö, A., Räike, A., Tattari, S., & Vehviläinen, B. (2016). A National-Scale Nutrient Loading Model for Finnish

Watersheds—VEMALA. Environmental Modeling and Assessment, 21(1), 83–109. https://doi.org/10.1007/s10666-015-9470-6

Johnsson,H., Bergström, L. and Jansson, P-E. 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. Agriculture, Ecosystems and Environment. 18:333-356.

Rekolainen, S., Pitkänen, H., Bleeke, A. & Felix, S. 1995. Nitrogen and phosphorus fluxes from Finnish agricultural areas to the Baltic Sea. Nordic Hydrology 26: 55-72.

Tattari, S., Bärlund, I., Rekolainen, S., Posch, M., Siimes, K., Tuhkanen, H-R. and Yli-Halla, M. 2001. Modelling field-scale sediment yield and phosphorus transport in Finnish clayey soils. Transactions of the ASAE.

Vuorenmaa, J., Rekolainen, S., Lepistö, A., Kenttämies, K. & Kauppila, P. 2001. Losses of nitrogen and phosphorus from agricultural and forest areas in Finland during the 1980s and 1990s. Environmental Monitoring & Assessment. (accepted).

7. Germany

Applied methodology for the PLC 7 assessment from GERMANY

by Antje Ullrich, Christoph Rummel and Wera Leujak, German Environment Agency (UBA)

Calculation of flow and loads (rivers, direct point sources)

Flow and river loads

The load calculations made for German rivers correspond to the recommendations of the PLC-6 Guidelines.

There are numerous and generally, quite small rivers that drain the German Baltic Sea catchment area. Not all of them are monitored and the number of monitored rivers may vary from year to year. For PLC-8 Germany reported 24 monitored rivers which cover about 66 % (about 16.000 km² including the national area of the Stettiner Haff) of the German Baltic Sea catchment area (except the transboundary German catchment area of the river Oder).

The annual load calculations are based on daily river flows and water quality samples that are taken between 10 to 24 times per year. Both German federal states ("Bundesländer"), Schleswig-Holstein and Mecklenburg-Vorpommern, calculate the river loads using the averaged monthly flow and mean monthly concentration of the respective nutrients.

Direct point source loads

Germany reported 29 municipal and 3 industrial direct dischargers. There are no directly discharging freshwater fish farms in the German Baltic Sea region.

The flow is measured continuously and concentrations are determined frequently. The frequency of sampling is determined by law or technical regulations and usually depends on the size of the facility and the substance in question. The measurements are carried out by the operator of the plant, the responsible federal state authorities or accredited laboratories according to standardized DIN procedures.

Inputs from unmonitored areas

Altogether about 34 % (about 8.100 km²) of the German Baltic Sea catchment area is not monitored (about 33 % in WEB and about 30 % in BAP (including German catchment area of the Stettiner Haff)).

For annual reporting calculations of inputs are based on flow and loads from monitored areas assuming similar conditions (concerning inputs from point and diffuse sources) prevailing in unmonitored areas. Loads calculated for all monitored areas are assigned to the unmonitored area based on their proportion. This method may lead to an over- or underestimation of inputs.

For periodical reporting the MoRE (Modelling of Regionalized Emissions; Research - Methods - MoRE (kit.edu); Pollutant emissions into surface waters | Umweltbundesamt; Fuchs et al. 2011, 2017) model was used to calculate flow and loads for unmonitored areas. MoRE calculates pathway-oriented nutrient and pollutant inputs to surface waters independent of whether the area is monitored or unmonitored (see the following paragraph: "source oriented apportionment"). All relevant pathways (including all point sources (MWWTPs > 50 PE (population equivalent) and scattered dwellings (defined ≤ 50 PE – individual system) and the relevant diffuse pathways) are included.

Source apportionment (load and source oriented approach)

Germany generally applies the source oriented approach using nutrient input results from the MoRE model.

The MoRE model is a free software tool for an empirical-based quantification of annual nutrient and pollutant emissions in river basins (Fuchs et al. 2017). It allows a regional and pathway specific quantification for any given aggregation unit. MoRE is based on the MONERIS concept that was developed for modelling of nutrient emissions into the water bodies (Behrendt et al. 2000). The model was later extended to include pollutant emissions.

The considered pathways can be classified into three blocks (Figure 1):

- Pathway-dependent on point-source
    - municipal wastewater treatment plants (MWWTP)
    - Industrial dischargers
- Pathway-dependent on diffuse non-urban sources and
    - Surface runoff
    - Erosion
    - Groundwater
    - Tile drainage
    - Direct atmospheric deposition onto surface waters
- Pathway-dependent on diffuse urban sources
    - Storm water sewer overflows
    - Combined sewage overflows
    - Small wastewater treatment plants (individual systems e.g. septic tanks).

MoRE calculates the inputs based on analytical units (average size 130-150 km²) based on the drainage network. The analytical units can be aggregated to different administrative units, hydrological subbasins, river basins or marine catchment areas.

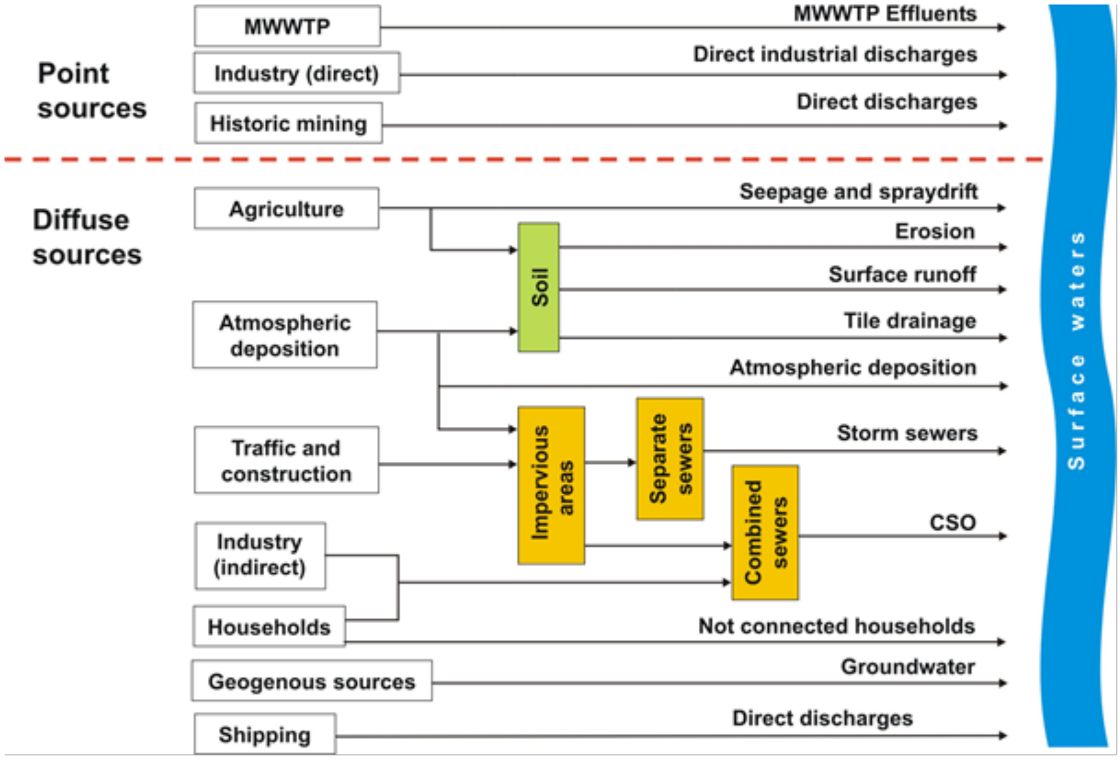

Figure 1. Sources and emission pathways considered in MoRE model (Fuchs et al. 2010; European Commission 2012, Fuchs et al. 2017).

The calculation of emissions from point sources can be straightforward, as data on effluent concentration and the amount of treated wastewater are available or can be derived from statistical data with the required accuracy.

The inputs caused by diffuse non-urban sources are the result of more or less complex interactions with different interfaces, including temporal storage, transformation and losses. These processes have to be integrated adequately into the approaches. Pathways from agricultural diffuse sources include erosion, surface run-off, tile drainage, seepage and spray drift. To calculate direct atmospheric deposition onto surface waters e.g. EMEP products (ecosystem specific deposition) are used. Atmospheric deposition onto land surfaces is not considered separately but included into the other emission pathways (e.g. in surplus calculation for agricultural lands).

The diffuse urban pathways account for various sources including air pollution, wastewater from industries and households as well as primary emissions from construction material and traffic.

To estimate natural background losses of nutrients a separate model scenario was defined, and a MoRE simulation was run. The scenario was defined as pristine. Therefore, the entire German Baltic Sea catchment area (except water surfaces) was assumed to be completely forested without any anthropogenic activity (no fortified area, no population, no point sources). Taking into account obvious lower atmospheric deposition either onto surface waters or onto land surface, nutrient emissions were calculated. Hydrologic conditions were assumed to be unchanged from today.

To satisfy the requirements of the load-oriented approach the MoRE results could be used as well. Actually, the model itself does not distinguish between load-oriented and source-oriented approach. However, taking retention into account the proportions of calculated pathways could be used to apply the load-oriented approach.

Retention

The MoRE model considers riverine retention based on sub-basin specific retention factors (Behrendt and Opitz, 1999). Other retention processes (in soils, groundwater, …) are indirectly includes in the pathway calculations.

Transboundary inputs

In Germany there is one transboundary river, the river Oder. The river Oder enters the Baltic Sea on the territory of Poland. The German territory covers 4.7 % of the entire catchment area operating two hydrochemical (one of them on PL border) and three hydrological stations. The Oder is crossing from Poland into Germany and back to Poland and is bordering the two Countries for some reaches. Therefore, German monitoring stations do not represent inputs only from Germany. To estimate transboundary inputs coming from the German territory, agreed proportions of total TP (8.5 %) and TN (3.7 %) inputs are used.

Uncertainty on flow, loads, unmonitored and total inputs and on sources

Uncertainties were estimated based on expert judgement.

References

Behrendt, H. and Opitz, D. (1999): Retention of nutrients in river systems: dependence on specific runoff and hydraulic load. Hydrobiologica Volume 410, pp 111-122.

Behrendt, H., Huber, P., Kornmilch, M, Ley, M., Opitz, D., Schmoll, O., Scholz, G. & Uebe,R. (2000): Nutrient Emissions into River Basins. UBA-Texte, 23/00

Fuchs, S., Scherer, U., Wander, R., Behrendt, H., Venohr, M., Opitz, D., Hillenbrand, Th., Marscheider-Weidemann, F., Götz, Th. (2010): Calculation of Emissions into Rivers in Germany using the MONERIS Model. Nutrients, heavy metals and polycyclic aromatic hydrocarbons. UBA-Texte 46/2010, Dessau

Fuchs, S., Wander, R., Rogozina, T., Hilgert, S. (2011): The MoRE Handbook. Karlsruhe Institute of Technology. Institute for Water and River Basin Management. http://isww.iwg.kit.edu/MoRE.php

Fuchs, S.; Kaiser, M.; Kiemle, L.; Kittlaus, S.; Rothvoß, S.; Toshovski, S.; Wagner, A.; Wander, R.; Weber, T.; Ziegler, S. (2017): Modeling of Regionalized Emissions (MoRE) into Water Bodies: An Open-Source River Basin Management System. Water 2017, 9, 239, doi:10.3390/w9040239.

European Commition (2012): Common Implementation Strategy for the Water Framework Directive (2000/60/EC) (2010) - Guidance Document No. 28, Technical Guidance on the Preparation of an Inventory of Emissions, Discharges and Losses of Priority and Priority Hazardous Substances

8. Latvia

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Calculation of flow and loads (rivers, direct point sources)

Water flow is calculated from the automatic measurements of water level and manual water discharge measurements in the main hydrological phases.

Riverine loads are calculated as follows:

$$L = \sum_{i=1}^{12} W \, x \, C$$

W – volume of monthly runoff based on average monthly discharge;
C – monthly water concentration (monthly discrete samples)

Data on point sources are obtained from the national data base "Ūdens-2" (Water-2). Pollution loads there are reported by the operators of waste-water treatment plants.

Inputs from unmonitored areas

Load from unmonitored areas was estimated by areal extrapolation of the monitored load in the upstream or neighbouring catchments with similar natural conditions and anthropogenic pressures.

$L_{unmon} = L_{mon}/A_{mon} * A_{unmon}$,

where: L_{unmon} = unmonitored load (t/y, kg/y)
L_{mon} = monitored load (t/y, kg/y)
A_{mon} = area of the monitored catchment (km^2)
A_{unmon} = area of the unmonitored catchment (km^2)

Source apportionment (load and source oriented approach)

Load oriented approach was used as described in the HELCOM Guidelines for Waterborne Pollution Inputs to the Baltic Sea (chapter 10).
Data on point sources are obtained from the national data base "Ūdens-2" (Water-2). Operators of municipal and industrial wastewater treatment plants and several fish farms have to quantify and report the pollution loads to the data base according to the requirements of polluting permits. Sampling frequency of polluting substances varies from one to twelve times per year. Wastewater volume in larger WWTPs are measured by flow meters and it is estimated in smaller WWTPs. Loads by rainwater is partly included the estimation of point sources. The rest is not quantified.

Inputs from scattered dwellings are not quantified.

Export coefficients of Ntot and Ptot from diffuse background sources (forest territories) were obtained from the Latvian State Forest Research Institute "Silava". Export coefficients are then multiplied by the area of forest and wetland in the sub-basin.

Atmospheric deposition on inland fresh water is not estimated.

Retention

Retention was calculated following Behrendt and Opitz (1999):

Retention coefficient for nitrogen: R_{SN}=6.3((Q*86,4*0.365)/As$^{)-0.78}$

Retention coefficient for phosphorus: R_{SN}=4,7((Q*86,4*0.365)/As) $^{-0.76}$

where Q is a discharge and area of surface waters in catchment As=A_{lake}+0.001*$A^{1.185}$ (A_{lake} – area of lakes in a catchment, A area of a catchment).

Retention R = $R_{SN,SP}$*Load

Transboundary inputs

Transboundary loads are important for the Rivers Bārta, Venta, Lielupe, and Daugava. At first, measured monthly concentrations at the border station and extrapolated discharges are used to calculate yearly load coming from a neighbouring country. In the case of the Daugava Rivers, the load is distributed between RU and BY by taking into the account the catchment area in these countries as well as the estimates of retention from the Tables 8.2. and 8.3 in "Guidelines for Waterborne Pollution Inputs to the Baltic Sea".

Uncertainty on flow, loads, unmonitored and total inputs and on sources

In stations, where both hydrochemical and hydrological observations are carried out at the same spot, the uncertainty in flow measurements was estimated to be 7 %: IRBE at VICAKI, BARTA at DUKUPJI. In rest of the hydrological stations, the uncertainty in flow measurements was estimated to be 12 %.

Uncertainty of monitored loads and sources was not estimated.

References

Behrendt H., Opitz D. (1999) Retention of nutrients in river systems: dependence on specific runoff and hydraulic load. In Man and River Systems (pp. 111-122). Springer Netherlands.

HELCOM Guidelines for the annual and periodical compilation and reporting of waterborne pollution inputs to the Baltic Sea (PLC-Water). HELCOM (2022). Available:

9. Lithuania

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Calculation of flow and loads (rivers, direct point sources)

Lithuania uses two separate approaches for calculating data required for annual and periodic reporting. Annual flows and loads are calculated from daily river water flow and monthly water quality monitoring data using formulas provided in PLC guidelines. Daily water flow is recalculated to monthly flow averages. Averaged monthly flow and monthly concentrations are used in load calculation (PLC guidelines formula 4.2). As it comes to direct point sources, they are few. Yearly data about them are provided by companies or municipalities responsible for those point sources.

For periodic reporting flow and loads are calculated using the SWAT+ model. The model has been prepared for all Lithuanian territory with the most detailed data available in the country. Model and its preparation are described in a series of model preparation documentation (document 1, document 2, document 3).

Additional model and data preparation steps, which are not described in the model preparation documentation, are presented below:

1. Additional data for years 2020 and 2021 (depending on parameter) were collected in order to extend model simulation period up to the end of year 2021. Data were collected on point sources, meteorological conditions (wind, temperature, precipitation, dew point, solar radiation) in weather stations, hydrological conditions (water flow) and water quality State monitoring data, detailed landuse and crops data, livestock data, atmospheric deposition information (EMEP latest data);
2. All the data was transformed to the formats and forms usable by the modeling system;
3. The final version of prepared model was run from 1994 to 2021. However, only the last year was used in the reporting;
4. Required loads and water flow results were extracted using prepared scripts in the modeling system:
    a. Loads coming to water bodies from different land uses were extracted;
    b. Routing of the loads was done through the river system, recording retention and apportionment;
    c. Water flows in the rivers were extracted;
    d. Extracted results per sub-basin (1842 sub-basins were used in prepared model for Lithuanian territory) were assigned to the following river basins used in reporting to HELCOM: Venta, Barta, Lielupe, Daugava, Pregolya, Nemunas, Akmena-Dane, Sventoji and BALTLAND. Additionally, all outlets to other countries and the Baltic Sea were identified.
5. Atmospheric loads were included into non-point source loads and not tracked or reported separately.

6. Finally, loads calculated from modelling results were rescaled to mirror the reported annual data, which were calculated from monitoring results. This was done by calculating coefficient of difference between monitoring and modeling results, and by using this coefficient modeling results were increased or decrease for non-point sources in each reported basin to receive the same loads at river mouths as in annually reported data.

Inputs from unmonitored areas

Loads and flow from unmonitored areas for annual reporting used to be calculated using area proportional method described in the guidelines (PLC guidelines formula 7.1). Minija river (neighboring basin to the unmonitored areas) concentrations and flow at the outflow used to be applied together with Minija and unmonitored areas area ratio to calculate loads from unmonitored areas. Meanwhile in the periodic reporting modeling approach was and is used to calculate loads and flows from unmonitored areas. However, for 2021 annual report the modelling approach was applied for calculating loads coming from the unmonitored BALTLAND basin, since the previous approach seem to largely overestimate the actual loads from BALTLAND. This seems to be the case because of the sink effect of the Nemunas delta (part of BALTLAND), which results in total neutralization of all loads, partly including also upstream loads. Alignment of approaches for annual and periodic report for BALTLAND helped to achieve consistency among reports.

Source apportionment (load- and source-oriented approach

Source apportionment data were prepared using model results. The model is loaded with physical data about environment, climate, discharges of point sources, agricultural activities, etc. Since SWAT+ model is in the category of physically based and semi-distributed parameters catchment models, processes occurring in the environment are simulated by the model. All sources apportionment data are based on simulation results.

Retention

Retention in the Lithuanian HELCOM river basins have been calculated using modeling. The routing of pollutants from different sources has been tracked through the river network. This allowed calculating retention of nutrients as well as track pollutants' retention by sources. The SWAT+ model is based on physical parameters. It simulates processes occurring in the river channel as diffusion, sedimentation, resuspension, break down of pollutants, etc. Thus, total retention is based on simulation of those processes occurring in the river.

It should be noted, that retention in unmonitored areas (BALTLAND basin) appeared to exceed generated catchment load. In order to avoid negative values, retention in the Nemunas delta region (part of BALTLAND area) has been technically transferred upstream and added to the Nemunas basin retention, resulting in final lower apportionment (load) value for the Nemunas basin accordingly. The remaining retention in the non-delta part of unmonitored area constituted the final retention value for the BALTLAND basin. In this way Nemunas delta apportionment (load) values corresponded with its catchment load values, while in the remainder of BALTLAND this is not the case.

Transboundary inputs:

Modeling has been used to calculate reported transboundary loads and flows needed in the periodic reporting. In contrast to annual report, where transboundary loads were considered as those entering Lithuania from abroad (Nemunas and Neris from Belarus, Sventoji from Latvia) and calculated from monitoring data, in this periodic report loads from Lithuania to other countries were treated as transboundary ones. In this respect, transboundary loads were modelled for Venta, Barta and Lielupe basins to represent flows to Latvia, as well as for Pregolya to represent flows to Russia (Kaliningrad region). It should be noted, that transboundary flows from Nemunas to Russia also exists, and it diverts roughly 20 % of upstream flow via the Matrosovka channel and as such it has not been reported separately as a transboundary flow previously (in periodic report in 2017). Due to complexities involved in the calculation of such flows (no monitoring station at this outflow) and the need to arrive at harmonized methodology on the HELCOM level, this periodic report does account for this transboundary outflow as well. This is planned for future periodic reports, although it was estimated for internal use by using modelling approach, calculated water flows from the Hydrometeorological Service and pollutant concentration data at the most downstream monitoring station of the Nemunas river (which is used for annual reporting).

Uncertainty on flow, loads, unmonitored and total inputs and on sources

Uncertainties on flow or loads have not been calculated or reported by Lithuania.

10. Poland

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1. GENERAL

The Polish PLC-8 report summarizes the balance of nutrient loads discharged by rivers into the Baltic Sea, so it is entirely concerned with pollution entering Polish rivers and lakes from within the country, as well as from outside Poland, via transboundary rivers.

The PLC-8 was developed in accordance with the updated HELCOM guidelines issued in 2022, "Guidelines for the annual and periodical compilation and reporting of waterborne pollution inputs to the Baltic Sea (PLC -Water)" [7]. These guidelines are not fundamentally different from those in place for the development of the PLC-7, and also leave a lot of leeway in terms of how to model the transport of pollutants, but impose a strict categorization of sources and a requirement to estimate river retention, which is tantamount to having to estimate loads at source as loads at the river interface.

In order to meet the requirements of the HELCOM guidelines and at the same time to ensure maximum comparability of the results with the results of the PLC-7, including previous balances recalculated according to the PLC-7 methodology, relied on the methodology developed for the Polish PLC-7 report.

Minor methodological changes were introduced. In addition to the advantage of comparability with previous PLCs, the strengths of this methodology are the well identified sources of data and information to create a HELCOM-compliant model, and the pollutant transport model itself, based on the mass balance method using spreadsheets, a method that seems most suitable when there are large data gaps for most pollutant source categories.

On the technical side, calculations for the PLC-8 were made in a series of related spreadsheets, grouping primarily: source data (river flows, nutrient concentrations in rivers, nutrient concentrations in groundwater, atmospheric precipitation, lists of municipal treatment plants, etc.), results of land use analyses, calculations of loads at source for individual source categories, and calculations of river retention and allocation of loads at source to river loads.

1.1 Reporting year

Unless otherwise stated, all Polish data covers the year 2021.

1.2 Monitored riverine flows and riverine loads

All the reported monitored catchment area flows are based on daily flow measurements. Concentrations of nutrients and heavy metals in rivers except the Vistula and Oder were measured monthly. Reported monitored area loads were calculated as the sum of the products of monthly flows and corresponding concentrations (flow-concentration or flow-load regressions were not used to estimate annual loads).

1.3 Division into sub-catchments

In the case of Poland, the HELCOM division into sub-catchments includes 31 units. According to the document received from HELCOM titled "What is not mentioned in the PLC Water Guideline" [1], loads from these sub-catchments are not the subject of the PLC-8 report. However, they are necessary for calculating both retention and allocation of river loads entering the Baltic Sea from Polish territory. This is because the omission in the calculations of loads flowing into Poland from abroad would have to mean that these loads would have to be allocated to sources within the Polish borders.

1.4 Land cover data

All land cover data used in the Polish PLC-7 report come from Corine Land Cover 2018 [8] which is the most up-to-date small scale source covering the whole country.

1.5 Unmonitored areas

For most of the computation catchments, it is impossible to reliably estimate riverine loads. These circumstances make it clear that with the current methodology, which according to the Contractor's bid is a continuation of the methodology used in the PLC-7, and with the current layout of chemical and flow monitoring stations, the usefulness of the division into computation catchments for the PLC reporting purposes is questionable. The exception is the computation catchments covering the unmonitored areas of the HELCOM SCPL00027 BAPPLLAND sub-catchment. This sub-catchment is very extensive (more than 10,000 km2), and its division into computation catchments facilitates the estimation of loads by virtue of the fact that flows, loads and retention rates for the sub-catchments of the monitored Coastal Belt rivers can be used more reliably to estimate flows and loads from small, adjacent computation catchments than to estimate flows and loads from the large and highly diverse BAPPLLAND area. Nonetheless, loads at source were estimated for all of the computation catchments.

2. QUANTIFICATION OF SOURCES IN MONITORED AREAS

2.1 Indirect municipal point sources (I_MUN)

The primary source of data on municipal point sources is the 2021 report on the implementation of the National Urban Wastewater Treatment Program (KPOŚK) [9]. This document includes about 1,700 treatment plants serving agglomerations designated in accordance with Directive 91/271/EEC on the treatment of municipal wastewater.

A large part (majority) of the wastewater treatment plants included in the KPOŚK reports are small facilities, discharging wastewater to receiving bodies other than lakes, and thus not required by water permits to monitor nitrogen and phosphorus. For such facilities, it was necessary to apply methods for estimating the nutrient load on the basis of available data, including primarily the BOD5 load in raw wastewater, the number of residents, the volume of wastewater, the BOD5 load

in treated wastewater and information on the type of treatment plant. For the purpose of these estimates, based on data from nearly 500 wastewater treatment plants that provided complete and reliable data on nutrient loads in raw wastewater, the nitrogen-to-BOD5 and phosphorus-to-BOD5 ratios of average unit loads of nitrogen and phosphorus in raw wastewater were calculated.

However, since the data indicated quite significant differences between larger (above 10,000 RM) and smaller WWTPs (higher N/BOD_5 and P/BOD_5 ratios), the average values of N/BOD_5 and P/BOD_5 ratios in raw wastewater from 193 WWTPs with up to 10,000 PE were ultimately used to estimate the loads discharged from small WWTPs. These ratios were 0.274 and 0.034, respectively.

A series of rules have been used to estimate nutrient loads from small wastewater treatment plants, assigning specific reduction values or specific N and P concentrations depending on the input data (PE, BOD at the outfall, treatment method, etc.). This is, in essence, a repetition of the approach that was used in the PLC-7. The continuation of this aspect of the methodology is very important, because a change in assumptions can result in significant differences in estimated loads. In the absence of other, more reliable indications of the effectiveness of nutrient reduction in small WWTPs that do not monitor nutrients, reduction factors of 0.65 and 0.35 were used for nitrogen and phosphorus, respectively, as in the PLC-7. These reductions are typical of the modified Lutzak-Ettinger activated sludge (MLE) process, which is the most common process in small municipal wastewater treatment plants in Poland.

Only a small percentage of Poland's municipal wastewater goes to municipal wastewater treatment plants not covered by the KPOŚK. As part of the work on the PLC-8, it was estimated that these WWTPs account for 5% of the nitrogen load and 11% of the phosphorus load from municipal sources. Due to statistical secrecy, it is virtually impossible to obtain the individual OS-3 reports submitted by these WWTPs to the Central Statistical Office.

Optional parameters in HELCOM reporting for municipal point sources are loads of heavy metals: mercury, cadmium and lead. However, the PLC reports and CSO BDL data for the NUTS-5 level do not contain information on the loads of these elements discharged with municipal wastewater into inland waters. Due to the lack of more recent data, during the preparation of the PLC-8, the primary source of information on the discharge was the "Lists of emission volumes and concentrations of priority substances and other pollutants" [11] used at PLC-7 and containing data from 2015-2017. As a rule, the PLC-7 included 2017 data, but in the absence of such data, available data from earlier years was used [5].

The PLC- 8 includes heavy metal loads of mercury, cadmium, lead, copper, nickel and chromium.

In addition, the PLC-8 for municipal point sources serving agglomerations includes the following pollutants: BOD5, COD - Cr, total suspended solids. The data on these pollutant loads were obtained from the KPOŚK report [9].

2.2 Indirect industrial sources (I_IND)

Due to statistical confidentiality regulations it was impossible to access data on individual industrial WWTPs with the exception of those which are included in the National Pollution Release and Transfer Register (PRTR). However, since the PRTR only includes releases of more than 50,000 kg N/y and more than 5,000 kg P/y, this source is incomplete even with regard to the plants included in it, as in a number of cases the plants only exceed one of the two thresholds and therefore only report one of the nutrients. A part of the work on PLC-7, some 250 top-priority industrial plants were selected and questionnaires were sent to them, hoping to obtain data information that would provide insight into the flows, input loads, treatment methods and treatment efficiencies of various industrial sectors. These data were to be used to estimate loads in treated wastewater from other plants representing these sectors, and ultimately to obtain complete, individualized information on industrial discharges. It turned out, however, that only a negligible number of plants provided responses, and some of these were incomplete. Ultimately, the results of the survey were not used in further work on the PLC-7.

Therefore, analogous to the work on PLC-7, the primary source of information on industrial discharges in the PLC-8 was the official statistical database at the municipality level (NUTS-5) [10] for N and P loads from about 2,500 municipalities. Many small industrial plants are not required to monitor and report loads of N and P. It is therefore certain that the loads from industrial sources reported in the Polish PLC-8 report are underestimated, but the level of underestimation is probably not too high, since many circumstances, including the spatial distribution of loads reported by the CSO, suggest that nitrogen and phosphorus discharge is highly concentrated in a small number of chemical industry plants.

N and P load data from industry for the NUTS-5 level were aggregated to the HELCOM sub-catchment level. For this purpose, individual NUTS-5 units (municipalities) were assigned to HELCOM sub-catchments. Municipalities crossed by sub-catchment boundaries were assigned to the catchment area in which the municipality's main town is located.

Optional parameters in HELCOM reporting for industrial point sources are loads of heavy metals: mercury, cadmium and lead. However, the CSO BDL data for the NUTS-5 level does not contain information on the loads of these elements discharged with industrial wastewater into waters. Due to the lack of more recent data, for the purpose of the PLC-8 report, the primary source of information on this discharge was the "Lists of Emissions and Concentrations of Priority Substances and Other Pollutants" [11] used for the PLC-7, updated in 2018 and containing data from 2015-2017. As a rule, the PLC-7 balance sheet included data from 2017, but in their absence, available data from earlier years were used.

The data reported in the PLC-7 has been updated with the results of the surveys received for 21 industrial wastewater treatment plants. Loads were attributed to aggregated sources of industrial pollution, corresponding to HELCOM sub-catchments. The PLC-8 takes account of loads of the following heavy metals: mercury, cadmium, lead, copper, nickel, and chromium.

2.3 Indirect aquaculture sources (I_AQS)

In Poland, by far the dominant forms of aquaculture are carp farming and salmonid fish farming (primarily rainbow trout). As part of the work on the PLC-7, the literature on nutrient discharge to water from carp farming was reviewed. Carp farming is usually carried out under semi-natural conditions (earthen ponds), and the production intensity usually does not exceed 1,500 kg/year - ha, so the water discharged from the ponds is not wastewater under current regulations, which means that it is generally not monitored for pollutants. The analysis of available data from research projects has not made it possible to clearly determine whether carp ponds act as sources or traps of nutrients [19, 20, 21]. Therefore, the Polish PLC-7 report omitted carp ponds, which amounts to the assumption that they have a net zero balance of nutrients. In the work on the PLC-8 this approach was maintained.

In the case of salmonid fish farming, due to statistical confidentiality regulations it was impossible to gain access to data on individual fish farms, which are submitted to the CSO in the form of RRW-22 reports. An attempt was made to obtain such data, as well as data on N and P concentrations in the feed and discharge waters of farm facilities, from the Salmonid Fish Producers Association, which keeps its own statistics in this regard. Ultimately, however, this attempt was unsuccessful. Therefore, as in the case of the PLC-7, the source of information on the volume of salmonid fish production was data from RR2-22 reports aggregated to the provincial level published in Fishery Announcements [12], noting that these data were for 2020. (data for 2021 are likely to be published in late 2023 and early 2023). The most authoritative available source of knowledge about the geographic distribution of breeding facilities was considered to be the data contained in the pressure database compiled for the implementation of the Water Framework Directive and taken from water permits [13]. Approx. 270 facilities listed in this source were assigned to specific provinces and HELCOM sub-catchments. In order to estimate the geographic distribution of production, it was assumed that the total production for a given province was distributed evenly among the facilities in that province, and based on this assumption, production in HELCOM sub-catchments was calculated. Since no fish feed data was available, N and P loads were estimated using unit loads of 60 kg N/ton of fish and 9 kg P/ton of fish. The unit loads are based on a survey of European (including Polish) publications on nutrient discharge from salmonid farms, done for the purposes of the PLC-7 [14, 15, 16, 17, 18]. Calculations of N and P loads are included in Attachment 13.

2.4 Natural background (NBS)

In the context of the Polish PLC-7, the term "natural background" is defined as referring to intact conditions where there are no anthropogenic pressures, including anthropogenic atmospheric deposition of nutrients. This is an approach in line with HELCOM guidelines. This concept of natural background was upheld in the PLC-8, and with it - the methodology for estimating loads corresponding to natural background. Taking into account the history of human-induced deforestation, in today's Poland the last time natural conditions dominated was 1-2 thousand years ago.

In the PLC-8, as in the PLC-7, natural background has been clearly separated from managed forestry and wasteland loads. Natural background concentrations of nutrients in waters feeding the river system have been assumed at 0.02 mg P/l (irrespective of soil type) and at 0.15 mg N/l, 0.36 mg N/l and 0.60 mg N/l for highly permeable, moderately permeable and poorly permeable soils, respectively. The distribution of the three distinguished soil permeability classes was adopted after the map found in the documentation of the PLC-6, prepared by IMGW [4]. This map was subjected to comparative analysis with soil maps as part of the work on the PLC-7 and was considered sufficient for the compilation. A value of 1.2 kg N/ha - year was assumed for the natural background of direct atmospheric deposition to waters (natural P deposition was omitted as insignificant). Natural background concentrations and loads were selected on the basis of a review of European and American literature on natural background concentrations in regions with comparative soil and climate conditions [22, 23, 25], data from relatively undisturbed small catchment areas [3] and global data on N deposition in pre-industrial period [24].

In the case of phosphorus, the calculation of background loads consisted of multiplying the background concentration by the flow of the in the final closing point of a given sub-catchment. In the case of nitrogen, the calculations were more complex due to the distinction of three background values depending on the permeability of the soils. The main elements of the calculations were:

- calculation of the areas occupied by each permeability category in a sub-catchment,
- calculation of the flows attributable to each permeability category of soils in a given sub-catchment, as a product of the flow in the sub-catchment and based on the ratio of the area of soils of a given category in the sub-catchment to the area of the entire sub-catchment,
- calculation of the flow inputs from a given sub-catchment as the sum of the products of concentrations and flows corresponding to the three categories of soil permeability in the sub-catchment
- calculation of the direct precipitation background as the product of the surface water area in a given sub-catchment and the unit background load (1.2 kg N/km^2 · r; 0.0 kg P/km^2 · r),
- summing up the background loads carried in the sub-catchment with flow and with direct atmospheric deposition.

2.5 Agriculture (AGS)

In the PLC-8, as in the PLC-6 and the PLC-7, estimates of losses from agriculture were based on the results of a state wide groundwater and tile drainage water monitoring programme under which nitrates and phosphates are measured in spring and autumn [26].

Loads from agriculture were estimated for all land falling into code category 2 of CLC2018.

Nitrogen

With regard to nitrates, mean concentrations from 934 monitoring points with data for both spring and summer were used. The number of monitoring points per HELCOM sub-catchment varied greatly, from 630 for the SCPL00023 (Vistula) to 0 for nine unmonitored parts of rivers. It is clear that with N concentrations strongly dependent on strictly local conditions (not least the fertilizer application rates on particular plots), only large datasets can be trusted to provide mean concentrations representative of the individual sub-catchments. Such datasets were available for Vistula (SCPL00023) and Oder (SCPL00009), but not for the remaining sub-catchments. Therefore, it was necessary to aggregate the small sub-catchment datasets so as to calculate more robust means, although this was obviously at the expense of ignoring any real differences between the sub-catchments. Therefore, data from the monitored sub-catchments of the smaller rivers were aggregated to obtain mean concentrations in the Lakeland Belt, while data from the unmonitored sub-catchments were aggregated to represent the Coastal Belt (Table 1).

Table 1. Mean nitrate nitrogen concentrations in farmland groundwater and tile drainage water in 2021.
Source: own study based on KSChR data

Area	Mean $N\text{-}NO_3$ concentration [mg N/l]	Number of monitoring points
Coastal Belt (BAPPLAND + unmonitored rivers)	3.18	28
Oder (SCPL00009) + Ina (SCPL00003)	9.13	244
Lakeland Belt (monitored lakeland rivers)	5.32	63
Vistula (SCPL00023)	7.09	738

Nitrates in farmland groundwater and tile drainage represent the majority, but not all of the nitrogen load from agriculture. In order to roughly account for the rest of the load, results of a MONERIS modelling exercise covering the period 2003-2008 [27] were used. According to that study, groundwater and tile drainage account for 85% and 90%, respectively, of the transport of N to surface waters in the Vistula and Oder basins, while the remaining 15% and 10%, respectively are accounted for by surface discharge and erosion. In order to take this into account, the nitrogen loads obtained by multiplying discharge from sub-catchment by the concentrations in Table 3 were further multiplied by appropriate factors.

The final step in the calculation of N loads from agriculture was to deduct natural background losses (see point 2.4 above) from the farmland loads.

Phosphorus

The approach to estimating phosphorus loads from agriculture was basically the same as in the case of nitrogen. There was, however, one major difference. Whereas in the case of N, groundwater and tile drainage water monitoring data for 2021 was available, in the case of P, it was not. Phosphate concentrations in the waters of agricultural areas were studied in 2012, 2016 and 2020. The data from these years were analysed with a view to the possibility that regularities could be discerned in them that would make it possible to forecast concentrations for 2021 based on them. No such regularities (trends) were identified, and therefore the results from 2020, as temporally closest to 2021 and in this sense the most authoritative, were adopted for further work. These results were used to calculate average concentrations for the four regions as in the case of nitrogen (Table 2).

Table 2. Mean phosphate phosphorus concentration in farmland groundwater and tile drainage water in 2020 used for load estimation for the year 2021. Source: own study based on KSChR data.

Area	$P\text{-}PO_4$ „proxy concentrations” [mg P/l]	Monitoring points
Coastal Belt (BAPPLAND + unmonitored rivers)	0.30	22
The Oder (SCPL00009) + the Ina (SCPL00003)	0.44	214
Lake Belt (monitored lake rivers)	0.26	68
The Vistula (SCPL00023)	0.22	629

Phosphate phosphorus in groundwater and tile drainage water represents only a part of the P load from farmland. As in the case of N, in order to roughly account for the rest of the load, results of a MONERIS modelling exercise covering the period 2003-2008 [27] were used. According to that study, groundwater and tile drainage account for 28% and 22%, respectively, of the transport of P to surface waters in the Vistula and Oder basins, while the remaining 72% and 78%, respectively are accounted for by surface flow and erosion.

In order to take this into account, the P loads obtained by multiplying sub-catchment discharge by the concentrations in Table 4 were further multiplied by appropriate factors, which amounted to 2.63 for the Vistula basin and 3.47 for the Oder basin. An intermediate value (3.01) was assumed for the remaining sub-catchments. Obviously, the resulting total loads were much higher than e.g. those reported in the previous PLC reports. However, these results did not take into account the fact that a large portion of the P loads associated with surface flow and erosion is irrelevant from the point of view of eutrophication, because it consists of particle-bound P which is not only non-bioavailable, but also sinks to the sediments of whichever water body it happens to enter. Thus, although this portion of the load may be recorded as entering surface waters, it in fact disappears from the water almost immediately upon entering. To account for this, the assumption was made, based on literature analysis [28, 29, 30, 31], that 90% of the P load from surface flow and erosion is immediately deposited in the sediments and/or is non-bioavailable and that only 10% should be included as relevant for the riverine load estimates. The opposite approach, i.e. the inclusion of particle-bound non-bioavailable P in the load calculations, would have resulted in very high overall P retention coefficients and in a gross overestimation of the real importance of agricultural sources of P.

The final step in the calculation of P loads from agriculture was to deduct natural background losses (see point 2.4 above) from the farmland loads.

2.6 Urban surface runoff and combined sewer overflows (SWS)

As part of the work on the Polish PLC-7 report, it was decided that the SWS category would include:

- discharges from storm overflows of the combined sewer system,
- rainwater and snowmelt discharged from managed areas included in Corine Land Cover 2018 Category 1 (cities, but also, among others, villages, mines, airports, etc.), regardless of whether these waters reach surface waters through storm sewers, surface flow or sub-surface flow.

This approach ensures that the compilation does not leave out any areas from which anthropogenic nutrient loads enter waters. Placing discharges from storm overflows in this category, rather than municipal point sources, avoided the complications of reporting individual discharges or creating another class of discharges aggregated in the "municipal point sources" category. Loads from discharges from storm overflows and from rainwater and snowmelt were, due to the different nature of these sources, estimated separately and only finally aggregated within the HELCOM sub-catchment. The following is a brief overview of how the loads were estimated, which is the same under the PLC- 8 as under the PLC-7.

Combined sewer overflows

Loads from combined sewer overflows are very difficult to estimate due to the very high dependence on strictly local technical (sewer and overflow characteristics) factors and weather (rainfall patterns). Correct estimation of loads is further hampered by the small amount of literature measurement data, especially from Poland. As a result of a review, during the work on the PLC-7, of this rather sparse literature [36, 37, 38, 39, 40, 41, 43], an approximate value of 5% of the total N and P load discharged into the combined sewer system was taken as the basis for estimating loads from storm overflows. This assumption was upheld in the PLC-8. Loads discharged to the combined sewer system were estimated based on the share of combined sewer length in the total sewer system (sanitary and combined sewer) in about 180 Polish cities and towns that have combined sewers with overflows. The source of the data on the length of the sewer system and the loads discharged by it was the 2021 report on the implementation of the KPOŚK. The results obtained for individual cities with combined sewers were aggregated to HELCOM sub-catchments.

Surface flow (including stormwater drainage)

Loads from surface flow in urban areas were estimated for all land belonging to code category 1 according to CLC2018. The area of these lands was calculated for each HELCOM sub-catchment. Based on the literature review, concentrations of 2.0 mg N /l and 0.35 mg P /l [32, 33, 34, 35] were assumed for surface flow waters (including those discharged through storm sewers) in the PLC-7. The same values were adopted in the PLC-8. Since all types of development were included in the calculations, as well as open-pit mines, airports, etc. (and not just the most densely built-up cities), a relatively low surface flow coefficient of 0.2 was used in the calculations (i.e., surface flow was assumed to account for an average of 20% of water flow from urban areas). The load from surface flow was calculated as the product of the assumed concentrations, the flow per land area of CLC2018 category 1, and the runoff coefficient of 0.2.

Interflow and ground flow

In addition to surface flow, sites included in code category 1 according to CLC2018 also generate interflow and ground flow, accounting on average for about 80% of the total flow. In order to account for N and P loads entering surface waters via these routes, reduction factors were applied to the above-mentioned concentrations so as to account for soil retention - for the 2021 data these factors were 17% and 68% for N and P, respectively (see Section 4.2.7). The natural background was subtracted from the obtained values. The concentrations obtained in this way were used to calculate loads as the product of these concentrations, the flow per land area of CLC2018 category 1, and a factor of 0.8

In the final step, the loads from storm overflows, surface flow, interflow and ground flow were summed for each HELCOM sub-catchment.

2.7 Scattered (unsewered) dwellings (SCS)

The number of population not connected to municipal wastewater treatment plants was determined for about 2,500 municipalities (NUTS-5 level) based on official statistics [10]. The population of each HELCOM sub-catchment was estimated based on spatial analysis, which involved assigning to HELCOM sub-catchments data on the un-sanitized population within the boundaries of each municipality. For municipalities intersected by HELCOM sub-catchment boundaries, an allocation of the unconnected population was made based on the ratio of the area of the municipality in the sub-catchment to the area of the entire municipality.

In the work on the PLC- 8, based on an analysis of available sources [2, 44], the following assumptions were made about wastewater from unsewered areas:

- 90% of households in unsewered areas use septic tanks, and the remaining 10% use various forms of domestic treatment plants, the most common of which is a sedimentation tank with sewage disposal to the ground,
- the percentage of wastewater that from unsewered areas goes to municipal treatment plants is 10%,
- about 90% of N and P loads from unsewered areas enter the ground,
- the average unit loads generated in households in unsewered areas are the same as in sewer connected areas (for 2021, based on data from nearly 500 treatment plants, they were estimated at 13.78 g N/M · d and 1.82 g P/M · d - see Attachment 9).

In addition, by analogy with the fate of nutrients from the surplus of agricultural fertilizers, it was estimated that about 17% of the N and about 6% of the P contained in wastewater released into the ground from unsewered areas ends up in surface waters.

The above assumptions made it possible to estimate loads from unsewered areas by multiplying the population of these areas in each sub-catchment by the corresponding coefficients.

2.8 Direct atmospheric deposition (ATS)

HELCOM requires analysis of N and P loads entering surface waters along with atmospheric deposition.

The following were used for loads calculation:

- data from PMŚ measurement stations monitoring atmospheric precipitation expressed in mass of N and P per unit area, in the form of digital modelling results (grid of squares in the form of high-resolution rasters) [45]
- surface water surface area in individual HELCOM sub-catchments.

The general scheme for calculating direct atmospheric deposition included:

- calculation of surface water area (category 5 in CLC2018) in individual HELCOM sub-catchments (spatial analysis),
- extrapolation of N and P deposition results from measuring stations to the entire area of Poland (atmospheric deposition map prepared on the basis of IDW extrapolation of data from GIOŚ/WIOŚ measuring stations,
- calculation of direct atmospheric deposition loads as a sum of products of unit loads and areas corresponding to these loads.

The use of IDW interpolation results allowed to obtain presumably more accurate estimates of direct atmospheric deposition of N and P to surface waters than in the PLC-7, where the Voronoi diagram was used to interpolate data from measurement stations.

2.9 Managed forestry and wasteland (MFS)

All land in code categories 3 and 4 of CLC2018 was taken into account in the estimate. In the PLC-4 [2], based on measured data from more than a dozen small Polish catchments dominated by forests and wastelands, a value of 0.038 mg P/ l for phosphorus was used to estimate loads from such areas, while for nitrogen the values of 0.31 mg N/ l, 0.75 mg N/ l and 1.22 mg N/ l were used for highly permeable, moderately permeable and poorly permeable soils, respectively. These values have since been used in Polish PLC reports and were also retained in the PLC-8.

The final step in the calculation of loads from forests and wasteland was to subtract natural background losses (see point 2.4 above).

2.10 Loads of unknown origin (UKS)

HELCOM methodology authorises the use of 'loads of unknown origin' category (UKS) if the loads observed cannot be assigned to any source. In the course of work on the PLC-8 a need to refer to that category did not arise.

3. SOURCES IN UNMONITORED AREAS

Sources in unmonitored areas were quantified in exactly the same way as sources in monitored areas (see item 4.4 above).

4. TRANSBOUNDARY LOADS

4.1 Incoming loads

Poland receives transboundary loads from the following sub-catchments:

- SCSL00001 Vistula (Slovakia)
- SCUA00001 Vistula (Ukraine)
- SCBY00004 Vistula (Belarus)
- SCCZ00001 Oder (Czech Republic)
- SCDE00035 Oder (Germany)

Loads from SCSL00001 were calculated based on the Dunajec and the Poprad rivers flow and concentration data provided by Slovakia. Data from the monitoring stations account for almost 100% of the Slovakian load.

Loads from SCUA00001 come from the catchments of the Bug and the San, both of which run partly along the Polish-Ukrainian border. The load from the Bug catchment was measured on the basis of flow and concentration data at the Włodawa H&C monitoring station and then the load originating from Ukraine was estimated based on Ukraine's share in the catchment area upstream from Włodawa. Since there are no suitable monitoring stations on the San, the load from the small Ukrainian part of the San catchment was estimated from the ratio of the Ukrainian parts of the San and the Bug (i.e. it was assumed that the unit loads per km^2 from the San are identical to those from the Bug).

Loads from SCBY00004 come mainly from the Bug catchment and partly from the Narew catchment. Due to non-availability of data from Krzyczew on the 2021 concentrations, the load from the Bug catchment was determined on the basis of flow data at Krzyczew monitoring station, data on flow and concentrations at the final section of the Krzna (Malowa Góra flow monitoring station and Krzna-Neple chemical monitoring station) and the data on concentrations in the Bug just above the Krzna (Bug Kuzawska/Kukuryki chemical monitoring station). Then the load originating from Belarus was estimated based on Belarusian share in the catchment area between Włodawa and Krzyczew. The monitoring station at Krzyczew is not ideally positioned (i.a. a small share of the load measured there is actually exported from Poland to Belarus and then reexported back to Poland), but it gives a fairly good approximation of the real situation. Since there are no suitable monitoring stations on the Narew, the load from the small Belarusian part of the Narew catchment was estimated based on the ratio of the Belarusian parts of the Narew and the Bug (i.e. it was assumed that the unit loads per km^2 from the Narew are identical to those from the Bug).

Loads from SCCZ00001 were estimated on the basis of flows and concentrations in the Oder (Chałupki H&C station) and the Olza (Łaziska H&C station) on the Polish side of the border. These two monitoring stations account for 75% of the area of SCCZ00001. The load from the unmonitored parts of SCCZ00001 (1804 km^2, mostly in the Sudeten Mountains) has not been taken into account in all of Poland's reporting to date so it has not been taken account of in the PLC-8.

Loads from SCDE00035 were estimated based on data from German regular reports. During the work on the PLC-7 it was determined that N and P loads at source from the SCDE00035 account for 3.66% and 8.52%, respectively, of the loads found in the Oder upstream from Gozdowice. Assuming that the retention ratios of riverine loads from both sides of the border are the same, this means that the shares of nitrogen and phosphorus loads from SCDE00035 in the structure of riverine loads at Gozdowice are also 3.66% and 8.52%. These ratios were used for the PLC-8.

4.2 Outgoing loads

Poland exports loads to Lithuania (the Nemunas SCPL00025) and Russia (the Pregolya SCPL00026).

From the point of view of Lithuania and Russia, respectively, these are the loads that would need to be included as a category of loads at source in order to then be able to correctly estimate the allocation of riverine loads at the mouths of the Nemunas and the Pregolya.

Of the 2512 km2 of the SCPL00025 sub-catchment, 1872 km2 are monitored on the Czarna Hańcza (Jałowy Róg H station and Śluza Kudrynki C station) and the Szeszupa (Poszeszupie H&C station).

Of the 7181 km2 of the SCPL00026 sub-catchment, 6749 km2 are monitored on the Łyna (Sępopol H station and Stopki C station), the Węgorapa (Mieduniszki H&C station) and the Guber (Prosna H station).

The river loads from the unmonitored parts of the Nemunas and the Pregolya were estimated using: source load data, flows estimated from the ratio of the area of the unmonitored to the monitored part, retention coefficients estimated as described in point 5 below.

5. RIVERINE RETENTION

Retention coefficients and retention of loads in monitored sub-catchments (including the monitored parts of Nemunas (SCPL00025) and Pregolya (SCPL00026), which discharge into the Baltic Sea outside Poland) were calculated using the mass balance method, i.e. retention was assumed to be equal to the difference between the sum of loads at sources and the load measured in the river.

Retention coefficients for the unmonitored sub-catchments (including the monitored parts of Nemunas (SCPL00025) and Pregolya (SCPL00026) were calculated as follows:

$R_U = R_M \cdot A_U/A_M$, where:

R_U - retention coefficient for the unmonitored sub-catchment

R_M - retention coefficient for the respective monitored sub-catchment

A_U - area of the unmonitored sub-catchment

A_M - area of the respective monitored sub-catchment

The R_U retention coefficients were applied only to sum of the loads from sources in the unmonitored sub-catchment and not to the loads from the upstream monitored sub-catchment. This is tantamount to the assumption that there is virtually no retention in the section of the river between the last monitoring station and the river mouth but that retention does take place within the unmonitored sub-catchment en route from the sources to the main river. This approach is consistent with that adopted in the Polish interim and annual reports to date and, it seems, with that of the other HELCOM States.

6. LOAD APPORTIONMENT

The loads reaching the Baltic Sea were apportioned according to their source using a method that assumes that the retention coefficients of nutrients from different sources are not equal. The sources have been divided into two groups, namely:

- Group 1: I_MUN, I_IND, I_AQU, ATS, TRS., i.e. municipal point sources, industrial point sources, aquaculture, atmospheric deposition and transboundary loads,
- Group 2: SWS, SCS, AGS, MFS, NBS, i.e. urban surface flow and overflows, wastewater from scattered (unsewered) dwellings, agriculture, managed forestry and wastelands and natural background loads.

Group 1 includes sources, the loads from which are discharged directly into surface waters, usually into rivers and lakes of substantial size. It may be said that in the case of these sources, soil retention and retention in very small water bodies (drainage ditches, small ponds, puddles etc.) plays virtually no role. This is also true for ATS, as ATS was only calculated for water bodies shown on the CLC2018 land use maps which only show relatively large lakes and rivers.

Group 2 includes sources, the loads from which must typically travel considerable distances through soil and/or along very small water courses in order to reach main rivers. This is only partly true for the SWS category, as combined sewer overflows (SCO) included in that category discharge wastewater straight into rivers, but this fact has been ignored for simplicity, because, according to the PLC-7 data, SCO events comprise less than 40% of the total SWS loads and the SWS loads comprise less than 1% and less than 2% of the total N and P source loads, respectively.

Riverine load apportionment was calculated according to two extreme scenarios:

- Scenario 1: retention coefficients for all the sources are equal, i.e. the fact that loads from Group 2 (e.g. agriculture or wasteland) need to travel long distances with groundwater or via very small water bodies does not increase their retention coefficients as measured at HELCOM catchment closing points;

- Scenario 2: retention coefficients for Group 1 are equal to 0 and all the retention observed is attributed only to Group 2 sources in proportion to the particular Group 2 loads.

The above scenarios, as well as any others regarding riverine load allocation, are not verifiable by direct measurements. However, it should be assumed that the actual picture of riverine load allocation is between these two scenarios.

Therefore, the average loads resulting from allocations according to the above two scenarios were taken as the final result of cargo allocation calculations.

7. LAND USE, FLOWS, CONCENTRATIONS, RIVERINE LOADS

Land use statistics according to CLC2018 were used as one of the basic input parameters for estimating area sources.

The reported unit loads and unit concentrations from unmonitored sub-catchments are significantly higher than those from monitored sub-catchments, and explaining the reason for this. First, in some cases, this is in fact due to the significantly higher density of loads at source in an unmonitored sub-catchment than in a monitored one, which in turn is most often related to the presence of a significant urban centre within a small area of the unmonitored catchment area.

Second, since the unmonitored parts are usually many times smaller than the monitored parts, the retention rates estimated for them are many times lower than in the monitored parts. This, of course, results in higher unit loads and concentrations.

It is important to note that discharge from the Pomeranian catchments are significantly higher than those from the Vistula and the Oder basins. This, of course, is very relevant to the results of calculating loads from area sources, specifically natural background (NBS), agriculture (AGS), forest and wasteland (MFS) and flow from urban areas (SWS), where the result depends on the area of land, discharge and concentration.

8. PLC-8 RESULTS

8.1 Loads At Source By Helcom Sub-Catchments

8.1.1 Indirect municipal point sources (I_MUN)

Compared to nitrogen, the distribution of phosphorus sources is such that a serious part of the load is discharged by small wastewater treatment plants, whose contribution to the nitrogen load is negligible. It is related to the fact that no matter what regulations are in force at any given time, it is much more difficult or even impossible to give up denitrification if this process has been built into the treatment plant, while it is very easy to give up (if only for economic reasons) chemical dephosphatation. This fact was taken into account by assuming that WWTPs which are not required to remove phosphorus do not carry out chemical dephosphatation.

8.1.2 Indirect industrial point sources (I_IND)

The average N:P ratio in treated industrial wastewater is very high (56:1) compared to the corresponding ratio in municipal wastewater (9:1). The difference is almost certainly due to the very large share of nitrogen fertilizer production in the structure of loads discharged from industrial wastewater treatment plants. It is possible that food industries, where the composition of wastewater is more similar to domestic wastewater, are responsible for comparable amounts of nitrogen and larger amounts of phosphorus than the fertilizer industry, but the vast majority of these loads enter waters through municipal treatment plants.

8.1.3 Indirect aquaculture sources (I_AQS)

It is worth noting the very strong concentration of loads in the sub-catchments of the Coastal Belt rivers. In some cases, loads per km2 of the sub-catchment are as much as 50 times the national average. The production of carp in Poland is comparable to that of trout, but existing data does not allow estimating loads from these fairly extensive farms.

8.1.4 Natural background (NBS)

It is worth noting elevated unit loads from the natural background in the sub-catchments of the Coastal Belt rivers. They are associated with significantly higher unit discharge in the catchments of these rivers than the lowland average. Particularly high unit background loads of nitrogen were estimated for several unmonitored (estuarine) sub-catchments of Pomeranian rivers, where high unit discharge is compounded by higher assumed background concentrations associated with the dominance of soils with reduced permeability.

8.1.5 Agriculture (AGS)

The estimated loads from agriculture for the land/inland water interface are significantly higher than loads from other source categories. The agricultural nitrogen load entering the waters from 1 km2 of Poland’s surface area corresponds to the load contained in raw sewage from approx. 130 people. In the case of phosphorus, the rate is 40 people. The population density in Poland is approx. 120 people/km2, the vast majority of whom are served by wastewater treatment systems. Variation in unit loads in the sub-catchments is relatively small, which is due to the fact that in all the sub-catchments agricultural land has a very large (usually dominant) share in the structure of use. The lowest unit loads were calculated for the Nemunas catchment, where three important factors coexist, i.e., relatively extensive agriculture, physiographic conditions conducive to slowing down the migration of pollutants (a large proportion of drainless areas, a significant share of land permanently covered with vegetation), and fairly low riverine discharge. The highest unit loads are found in Pomerania, which is associated chiefly with high riverine discharge.

8.1.6 Managed forestry and wasteland (MFS)

The unit loads from forests and wasteland are significantly higher in Pomeranian catchments than in the Vistula or Oder river basins, with this being due not only to the greater discharge from these areas, but also to their above-average forest cover.

8.1.7 Urban surface flow and combined sewer overflows (SWS)

The estimated loads include not only urban surface flow and overflows from combined sewer systems, but the entire nutrient loads from areas in Category 1 of the CLC2018 classification. This is because the source apportionment adopted by HELCOM does not, in principle, provide a separate place for loads contributed with interflow and groundwater flow from urbanized areas, or for loads from heavily transformed areas other than urban areas. On a national scale, under the assumptions used concerning i.a. natural background, the estimated N load in the SWS category consists of 41% of the load discharged by combined sewer overflows, 56% of the load contained in surface flow, and 3% of the load contained in interflow and groundflow. The analogous percentages for phosphorus are 34%, 66% and 0% (the load from interflow and ground flow approximates the background value).

8.1.8 Scattered (unsewered) dwellings (SCS)

The average nitrogen and phosphorus loads entering surface waters from one km2 of Poland’s surface area correspond to the loads contained in raw sewage generated by 5 and 2 people, respectively. This is approx. 25 times less than the unit loads going into water from agricultural areas.

8.1.9 Direct atmospheric deposition (ATS)

Differences between unit loads in particular sub-catchments result from relatively small differences in values of unit atmospheric deposition and sometimes extreme differences in the share of surface waters in sub-catchments. As a result, the biggest unit loads per km2 of catchment were calculated for unmonitored part of the Vistula catchment (SCPL00024), which covers a belt only approx. 1 km wide and for unmonitored part of the Łupawa catchment (SCPL00008), a vast part of which is taken by lake Gardno.

8.1.10 Transboundary loads (TRS)

The category of transboundary loads differs fundamentally from the other categories described above not only in that it concerns loads generated abroad, but also in that it is actually riverine loads measured or estimated at the border, rather than loads measured or estimated at the land/surface water interface. Loads measured or estimated for transboundary catchments at the land/surface water interface would be much higher, or more precisely, higher by the value of retention in transboundary inland waters.

8.1.11 Loads at source by HELCOM sub-catchments - summary

Total nitrogen loads entering Polish surface waters were estimated at 305.2 thousand tons of nitrogen and 15.4 thousand tons of phosphorus, of which 284.1 thousand tons and 14.3 thousand tons, respectively, come from the territory of Poland, with the remainder coming from transboundary catchments. The average unit loads from the Polish territory are 913 kg N/km2 and 46 kg P/km2. The highest unit loads (1580 kg N/km2 and 123 kg P/km2) were estimated for the SCPL00001 sub-catchment (monitored part of the Grabowa catchment). If we do not count transboundary catchments, the lowest unit loads were estimated for the Nemunas catchment, characterized by very low population, a high proportion of semi-natural elements, relatively extensive agriculture and low riverine discharge.

The agriculture is the absolute largest source responsible for two-thirds of both nitrogen (73%) and phosphorus (61%) reaching Polish surface waters. The second largest source, municipal wastewater treatment plants, accounts for only 7% of nitrogen and 16% of phosphorus. Transboundary loads rank third, with a share of 7% in the nitrogen apportionment and 5% in the phosphorus apportionment, followed closely by natural background contributing 4% to the nitrogen apportionment and 6% to the phosphorus apportionment. Domestic wastewater from unsewered dwellings accounts for only 4% of nitrogen and 3% of phosphorus.

From the "Vistula" region comes 57% of the nitrogen load, from the "Oder" region 27%, from the “Coastal Belt" region 7%, from the “Pregolya and Nemunas" region 2% and from the “Transboundary" region 7% of the nitrogen load reaching Polish inland waters. In all national regions, agriculture is by far the dominant source (74-80%). In the "Vistula" and the "Oder" regions, the share of discharges from municipal treatment plants reaches 7-9%, while in the other two regions the value amounts to approx. 6%. On the other hand, in the “Coastal Belt" and the “Pregolya and Namanus" regions, natural background plays an important role (7-9%). A peculiar feature of the “Coastal Belt" region is the noticeable share of aquaculture (6%).

It is noteworthy that there is a much smaller disproportion than in the case of nitrogen between the "Vistula" and the "Oder" regions, which account for 46% and 34% of the phosphorus load at source, respectively. The share of the “Coastal Belt" (10%) is significantly higher than the share of nitrogen, while the share of transboundary sources is the same (7%). The Pregolya and the Nemunas contribute only 3% of the phosphorus load reaching Polish surface waters.

As with nitrogen, phosphorus sources are heavily dominated by agriculture, the share of which varies from 62% in the Vistula region to 70% in the “Pregolya and Nemunas” region. The share of discharges from municipal wastewater treatment plants in the “Vistula” and the “Oder” regions is significantly higher than for nitrogen, at 19% and 16% respectively, while in the other two Polish regions it amounts to 9% for the Coastal Belt region and 15% in the “Pregolya and Nemunas” region. The share of natural background varies from 4% in the "Oder" region to 7% in the Vistula region. In the “Coastal Belt" region, aquaculture contributes 11% of the phosphorus entering surface waters. Domestic wastewater from unsewered dwellings contributes from mere 1% (“Nemunas and Pregolya", “Coastal Belt") to 4% ("Vistula") of phosphorus to surface waters.

8.2 Retention In Inland Waters And Riverine Load Apportionment

8.2.1 Retention in inland waters

The average retention coefficient of nitrogen loads reaching Polish inland waters was estimated at 0.52, with the monitored parts of the Vistula and Oder river basins having retention coefficients of 0.58 and 0.53, respectively. Attention is drawn to a high retention coefficient in the monitored Polish part of the Nemunas basin (0.35) despite not very large area of this sub-catchment. On the other hand, the retention coefficient in the unmonitored part of the Lupawa and the Vistula river basins is close to zero - this is the result of huge disproportion between the SCPL00024 and SCPL00023 sub-catchments areas.

The average retention coefficient of phosphorus loads amounts to 0.55, with the monitored parts of the Vistula and Oder river basins having retention coefficients of 0.44 and 0.76, respectively. It is worth noting that in the case of phosphorus, the proportions are reversed - the Oder River basin retains phosphorus more efficiently than the Vistula River basin. It is difficult to say whether these results reflect the actual state of affairs, or are perhaps the result of an overestimation of phosphorus loads entering the Oder. It is worth recalling that, guided by the results of the MONERIS model, a higher ratio of loads from surface flow and erosion to loads from groundwater flow was assumed for the Oder river basin than for the Vistula river basin.

8.2.2 Riverine load apportionment

Out of more than 146 thousand tons of nitrogen discharged into the Baltic Sea in 2021, 64.5% is estimated to have come from agriculture, 11.0% from municipal treatment plants, 10.4% from transboundary sources, 3.9% from natural background and 2.4% from domestic wastewater generated in unsewered dwellings. In the case of phosphorus, agriculture contributed 48.2% of the total load of 7,017 tons, municipal treatment plants contributed 25.4%, transboundary sources contributed 10.6%, natural background contributed 5.4% and domestic wastewater from unsewered dwellings contributed 2.2%. If we exclude sources that are practically beyond our control, i.e. natural background and transboundary loads, the share of the three largest sources will be as follows:

- for nitrogen: agriculture 75%, municipal treatment plants 13%, unsewered dwellings 4%
- for phosphorus: agriculture 57%, municipal treatment plants 30%, unsewered dwellings 3%.

The slightly smaller share of agriculture in the structure of riverine loads than in the structure of loads at source with slightly larger share of municipal treatment plants and transboundary loads at the same time, is a consequence of the adopting such solutions in the model that cause retention to vary depending on for how long a distance the loads of a certain category must cover to get to the main rivers. In the case of agriculture, as well as natural background, forests and wastewater from unsewered dwellings, the distance is longer on average than for point sources, atmospheric deposition or transboundary loads. This means that the model's resulting effective retention coefficients for pollutants from e.g. agriculture are higher than those from e.g. municipal discharges.

If transboundary and unmonitored sub-catchments are excluded, the share of agriculture in the sub-catchments' nitrogen load structure ranges from 71% for the Nemunas, 76% for the Ina.

The share of nitrogen from municipal treatment plants in the monitored sub-catchments ranges from 1.2% (the Wieprza) to 14.4% (the Oder). Outside the Vistula, the Oder and the Pregolya, the share of municipal wastewater in the nitrogen apportionment does not exceed 10%, and is usually much lower. Maximum share (64%) of municipal waste can be found in a very small unmonitored part of the Słupia catchment (SCPL00020), where there is a huge WWTP for the Słupsk agglomeration.

Wastewater from industrial treatment plants in most sub-catchments is of marginal importance. By far the largest share (4.1%) is observed in the monitored Vistula sub-catchment, which is undoubtedly related to the presence of large chemical plants, including the fertilizer industry.

Although aquaculture nitrogen is of marginal importance nationally, in some of the Coastal Belt rivers its share is not insignificant, and in the unmonitored Reda sub-catchment it reaches 38%.

The variation in phosphorus load structure in the Polish monitored sub-catchments is quite similar to that described for nitrogen. The share of agriculture varies from 28% (the Grabowa) to 66% (the Nemunas). In the monitored parts of the Vistula and the Oder river basins, it is 55% and 49%, respectively. Municipal wastewater treatment plants account for 27% and 41% of the phosphorus load in the Vistula and the Oder and only 4% in the Grabowa. In contrast, the share of aquaculture ranges from 0.6% in the Vistula and 0.5% in the Oder to as much as 62 % in the Grabowa, while in the Parsęta, Wieprza, Słupia, Łupawa, Łeba and Reda it varies from 22% to 49%. Domestic wastewater from unsewered dwellings contributes only 3% of phosphorus to the load apportionment of the Vistula, 2% to the Oder and generally less than 2% to the load apportionment of other rivers.

9. LOAD APPORTIONMENT AT THE LEVEL OF COMPUTATION CATCHMENTS

9.1 Interpolations For The Purposes Of Loads At Source Apportionment

9.1.1 Hydraulic computations

The highest discharge rates were calculated for Pomeranian first-order rivers and mountain rivers taking their origin in the highest parts of the Carpathian Mountains. Relatively high discharge was calculated for the rivers of the Sudeten Mountains, areas of the Vistula basin from the mountains to the San mouth and for some Lake District rivers. Very low discharge was calculated i.a. for southern Greater Poland, Lower Silesia and a part of Mazovia and Polesie.

9.1.2 Interpolation of nutrient concentration in groundwater

Shepard's approximation method (IDW) was used to address a large lack of data on nitrate concentrations in groundwater. As it can be seen, this operation yielded a dense grid of approximated values of nitrate nitrogen concentrations. However, this does not change the fact that we do not actually know what the real concentrations are. Analysis of the image obtained allows us to assume that in many places the interpolated data may deviate significantly from the real data. This applies especially to those catchments, in which the number of monitoring points is very low (e.g. the Drawa, Lower Oder, Myśla, Lower Warta).

Due to the lack of data for 2021, the estimation of phosphate concentrations was based on the 2020 data. The grid of points includes more than 1,000 points. However, there are regions where interpolation should be treated with great caution. These include the Lower Warta Valley and the Upper Warta Valley, where there are only isolated points.

9.1.3 Results of loads at source apportionment at the level of the computation catchments

The distribution of loads from municipal treatment plants (I_MUN) for nitrogen and phosphorus is very similar, which is due to fairly stable proportions between these elements in treated wastewater. The catchments with the highest unit loads are those within large agglomerations - the Upper Silesia region, the Vistula valley, the middle Warta, and the Ner.

Loads from industrial wastewater treatment plants (I_IND) are much more heavily concentrated along the big rivers - the Vistula and the Oder - and in some areas, especially in the lake districts, there are none.

Loads from aquaculture (I_AQU) are concentrated very strongly in Pomerania and to a much lesser extent in the Carpathian Foothills, and are almost absent in the rest of Poland.

Loads from flows from urban areas and from combined sewer overflows (SWS) occur in all catchments - note that the flow from rural households, among other things, is included here. However, there is a clear tendency to concentrations in catchments that have big cities - the catchments covering the Silesian Agglomeration, Warsaw, Gdansk, Lodz and Szczecin.

The distribution of loads from unsewered dwellings (SCS) is quite different. The highest load densities are found in central and southern Poland, where high population densities coexist with a high proportion of scattered development. However, catchments with very high loads from this source also include e.g. the Bystrzyca River catchment in Lower Silesia. The lowest unit loads of the SCS category are found in the northern lake districts, which can be linked to the relatively low population, a high emphasis on sewer development due i.a. to tourism, and perhaps a higher proportion of compact, more easily sewered buildings.

In the adopted calculation scheme, agricultural loads (AGS) depend equally on agricultural land area, nutrient concentrations in groundwater and unit discharge. Therefore, unit loads estimated for regions featuring intensive agriculture but low discharge, such as Lublin province, are by no means among the highest. High loads of phosphorus are primarily visible in Silesia, Pomerania, south-eastern Greater Poland and the Carpathian Foothills, which is undoubtedly due partly to elevated discharge rates. For nitrogen, the centre of gravity of the load distribution is shifted toward Kuyavia and northern Greater Poland. It is worth to underline that the 2021 distribution of loads from agriculture differed significantly from that in 2018 (PLC-7) [5], which illustrates a high lability of this largest source of nutrients.

Loads from atmospheric deposition (ATS) depend on concentrations in precipitation waters, the amount of precipitation and the surface area of inland waters, as only deposition directly to the water surface is considered. It is the water surface area that is the most differentiating factor in the distribution of loads - they are by far the highest in catchments abounding in lakes.

In the adopted calculation scheme, forest and wasteland loads (MFS) are a function of forest and wasteland area and the amount of unit discharge, and in the case of nitrogen, also a function of soil permeability. Hence, high unit load values are concentrated primarily in Pomerania and the Carpathians, where high forest cover goes hand in hand with high discharge rates. In contrast, the areas with the lowest product of forest cover and discharge coefficients, and thus the lowest loads from forests, are primarily southern Greater Poland and southern Mazovia. The modifying effect of soil permeability on nitrogen can be seen, among others, in the Sępopolska Lowlands, where the predominant clay soils contribute to increased loads from forests.

In the adopted calculation scheme, the distribution of unit loads from natural background (NBS) depends, in the case of nitrogen, on discharge rates and on the permeability of soils, and in the case of phosphorus - exclusively on discharge rates. For both elements, the area featuring the lowest unit loads includes the southwestern lowlands of southern Greater Poland, mid-Mazovia and Polesie, while mountainous and foothill areas feature high values. In the case of nitrogen, the modifying effect of soil permeability becomes apparent in the northern edges of Warmia and Mazuria which feature mostly poorly permeable clay soils.

There are very few cases where agriculture does not have an absolute majority in nitrogen loads. These include the Middle Vistula (a large share of municipal treatment plants and, in the case of nitrogen, industrial WWTPs), Middle Oder (municipal and industrial treatment plants) and Przemsza (municipal and industrial treatment plants, as well as combined sewer overflows and unsewered dwellings).

10. COMMENTS AND RECOMMENDATIONS FOR SUBSEQUENT REGULAR PLCS

Listed below are some courses of action worth taking in this regard.

1. It is necessary to synchronize the study of nutrients in rivers under the PMŚ with the PLC reporting cycle. Under the PMŚ, chemical monitoring stations have been established at practically all computation catchment closing points.
2. Consideration should be given to changing the layout of the computation catchments so that they correspond to the layout of active flow monitoring stations.

3. Phosphate monitoring in groundwater and drainage water should be synchronized with the PLC cycle. Lack of phosphate testing for 2021 and the resulting need to base calculations on data from previous year is a major shortcoming of the Polish PLC7 report.
4. All wastewater treatment plants should be required to monitor nitrogen and phosphorus, regardless of whether they are required by water permits to reduce these substances. Much of the nutrient loads from treatment plants is neither monitored nor reported.
5. It is necessary to find a solution that will make it possible to unambiguously assign loads from trout farming to computation catchments.
6. Efforts should be made to improve the model in the scope of apportioning loads from agriculture. The current method relies on the use of groundwater monitoring results and supplementary, MONERIS model-based, very coarse estimates of loads contributed with surface flow and erosion.

11 BIBLIOGRAPHY

1. Frank-Kamenetsky D. „PLC 8 Periodic reporting. What is not mentioned in PLC Water Guideline" . HELCOM, 2022
2. Dokumentacja prac nad polskimi bilansem PLC4
3. Dokumentacja prac nad polskim bilansem PLC5
4. Dokumentacja prac nad polskim bilansem PLC6
5. Dokumentacja prac nad polskim bilansem PLC7
6. Dane o przepływach w punktach wodowskazowych za 2021 r., pozyskane z IMGW
7. Svenson L. et. al. Guidelines for the annual and periodical compilation and reporting of waterborne pollution inputs to the Baltic Sea (PLC -Water). HELCOM 2015 -2022
8. https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download
9. Sprawozdanie z realizacji Krajowego Programu Oczyszczania Ścieków Komunalnych (KPOŚK) za 2021 r. PGW Wody Polskie, 2022
10. Bank Danych Lokalnych GUS https://bdl.stat.gov.pl/bdl/start
11. Dane z wykazów wielkości emisji i stężeń substancji priorytetowych oraz innych substancji zanieczyszczających, wykonane dla obszarów działalności poszczególnych RZGW, zestawione na potrzeby bilansu PLC7
12. Andrzej Lirski, Leszek Myszkowski - Polska akwakultura w 2020 roku na podstawie analizy kwestionariuszy statystycznych RRW-22. Część 1 (Komunikaty Rybackie 2021/06 i Część 2 (Komunikaty Rybackie 1/22)
13. Identyfikacja presji w regionach wodnych i na obszarach dorzeczy. DHI Polska Sp. z o.o. - Pectore- Eco Sp. z o.o. dla PGW Wody Polskie, 2019

14. Xinxin Wang et al. Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture. Aquacult Environ Interact, Vol. 2: 267–283, 2012
15. Lazzari R., Baldisserotto B. Nitrogen and phosphorus waste in fish farming. B. Inst. Pesca, São Paulo, 34(4): 591 - 600, 2008
16. Hernandez A. J., Roman D. Phosphorus and nitrogen utilization efficiency in rainbow trout (Oncorhynchus mykiss) fed diets with lupin (Lupinus albus) or soybean (Glycine max) meals as partial replacements to fish meal. Czech. Journ. Anim. Sci. 61, 2016 (2):67-74
17. Pulatsu S. et al. The Impact of Rainbow Trout Farm Effluents on Water Quality of Karasu Stream, Turkey. Turkish Journal of Fisheries and Aquatic Sciences 4: 09-15 (2004)
18. Teodorowicz M. Surface water quality and intensive fish culture (monograph). Arch. Pol. Fish. (2013) 21: 65-111
19. Knosche R. et al. Balances of phosphorus and nitrogen in carp ponds. Fisheries Management and Ecology, February 2000
20. Jahan P. et al. Phosphorus and nitrogen excretion during growth span of carp kept under two rearing systems. Fisheries Science 2003; 69: 431-437
21. Kufel L. Are fishponds really a trap for nutrients? – a critical comment on some papers presenting such a view. J. Water Land Dev. 2012, No. 17 (VII–XII): 39–44
22. Smith R.A. et al. Natural Background Concentrations of Nutrients in Streams and Rivers of the Conterminous United States. Environ. Sci. Technol., 2003, 37 (14), 3039-3047
23. Argerich A. et al. Trends in stream nitrogen concentrations for forested reference catchments across the USA. Environ. Res. Lett. 8 (2013)
24. Holland E. A et al. Contemporary and pre-industrial global nitrogen budgets. Biogeochemistry 46(1) July 1999
25. Leujak W., Urlich A. Natural Background – presentation. PLC 7 IG 7 Meeting, 14. – 16.05.2019 in Warsaw. Umwelt Bundesamt, 2019
26. Wyniki monitoringu azotanów i fosforanów w płytkich wodach gruntowych (2010-2021). Krajowa Stacja Chemiczno-Rolnicza
27. Pastuszak M. et al. Impact of forecasted changes in Polish e conomy (2015 and 2020) on nutrient emission into the river basins. Science of The Total Environment Volume 493, 15 September 2014, Pages 32-43
28. Risto Uusitalo et al. Particulate Phosphorus and Sediment in Surface Runoff and Drainflow from Clayey Soils. Journal of Environmental Quality 30(2):589-95, March 2001
29. Phosphorus: Transport to and availability in surface waters. University of Minnesota Extension https://extension.umn.edu

30. Reid K. et al. Components of Phosphorus Loss From Agricultural Landscapes, and How to Incorporate Them Into Risk Assessment Tools. Front. Earth Sci., 05 September 2018
31. Verheyen D. et al. Dissolved phosphorus transport from soil to surface water in catchments with different land use. AMBIO 2015, 44(Suppl. 2):S228–S240
32. Yang Y., Lusk M. G. Nutrients in Urban Stormwater Runoff: Current State of the Science and Potential Mitigation Options. Current Pollution Reports (2018) 4: 112–127
33. Yang Y., Toor G.S. Stormwater runoff driven phosphorus transport in an urban residential catchment: Implications for protecting water quality in urban watersheds. Scientific Reports (2018) 8:11681
34. Jani. J et. al. Composition of nitrogen in urban residential stormwater runoff: concentrations, loads and source characterization of nitrate and organic nitrogen. https://journals.plos.org/ February 28, 2020
35. Zębek E., Szwejkowska M. Ocena wpływu podczyszczonych ścieków deszczowych na liczebność sinic w śródmiejskim jeziorze Jeziorak Mały przy zróżnicowanej wysokości opadów atmosferycznych. Ochrona środowiska vol. 36, nr 1, 2014
36. Zawilski M., Brzezińska A. Bilans ścieków i ładunków zanieczyszczeń dopływających do oczyszczalni ścieków z uwzględnieniem mokrej pogody. Ochrona Środowiska, Rok 25 (2003), Nr 1
37. Brzezińska A. et al. Assessment of pollutant load emission from combined sewer overflow s based on the online monitoring. Envir on Monit Assess (2016) 188: 502
38. Mascher F. et al. Impact of Combined Sewer Overflow on Wastewater Treatment and Microbiological Quality of Rivers for Recreation. Water 2017, 9(11), 906
39. Barone L. et al. Analysis of the residual nutrient load from a combined sewer system in a watershed of a deep Italian lake. Journal of Hydrology 571 (2019) 202-213
40. Cools J. et al. Assessment of impact of storm water overflows from combined waste water collecting systems on water bodies (including the marine environment) in the 28 EU Member States. Final Report for Task 1.3. January 27, 2016
41. Cools J. et al. Assessment of impact of storm water overflows from combined waste water collecting systems on water bodies (including the marine environment) in the 28 EU Member States. Final Report for Task 1.4. January 27, 2016
42. Henley R. et. al. Review of BAT and BEP in Urban Wastewater Treatment Systems focusing on the reductions and prevention of stormwater related litter, including micro-plastics, entering the Marine Environment Prevention of stormwater related litter, including micro-plastics, entering the Marine Environment. OSPAR Commission, 2019.

43. Morgan D. et al. Technologies for Monitoring, Detecting and Treating Overflows from Urban Wastewater Networks. EPA Research. Climate – Water – Sustainability. Report no. 240. www.epa.ie
44. Gospodarka ściekowa gmin na obszarach nieobjętych systemem kanalizacji zbiorczej w latach 2009-2011 (i półrocze). Informacja o wynikach kontroli Nr ewid. 68/2012/P/11/133/ LKA. Najwyższa Izba Kontroli, 2012
45. Wyniki monitoringu depozycji atmosferycznej N i P za 2021 r., interpolowane na obszar Polski metodą IDW, w postaci plików rastrowych wysokiej rozdzielczości, pozyskane z GIOŚ
46. Dane z Państwowego Monitoringu Środowiska, przekazane przez Zamawiającego
47. Raport z wykonania map zagrożenia powodziowego i ryzyka powodziowego. Zadanie 1.3.2 Przygotowanie danych hydrologicznych w zakresie niezbędnym do modelowania hydraulicznego. IMGW, 2013

11. Russia

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In general, Russia follows the methodology described in the PLC-6 guidelines.

Calculation of flow and loads (rivers, direct point sources)

The annual monitored river discharges for nutrients were calculated by multiplying the monthly concentration by the monthly flow and summing up the monthly loads (equation 4.2 from the PLC-6 Guideline). Initial data (flow and concentrations values) provided within state monitoring. In cases, there some of the parameters are missing in the monitoring programme the specific estimates have been used (e.g. Pregolya river total nitrogen and total phosphorous concentrations were obtained from the BASE Project and Soils2Sea Project screening activities), as well as models (such as HYPE and FyrisNP).

Direct point sources load obtained from the state statistical reporting, based on the continuous measurements implemented by nature users.

Inputs from unmonitored areas

Estimation of the nutrient pollution from unmonitored areas has been implemented using HYPE and FyrisNP models.

Source apportionment (load and source oriented approach)

Source apportionment for big catchments like Neva and Narva rivers (case 1) implemented using Institute of Limnology Loading Model. HYPE and FyrisNP models were used to assess sources contribution in Kaliningrad region and smaller river cathcmnts belonging to the Gulf of Finland basin (case 2).

The basic components of the total annual load on catchment (Ltot) of Ptot and Ntot are the loads from point sources (Lp), diffuse load from agricultural production in the area (Lagr), diffuse emission of nutrients from various types of land surface not effected by agriculture (Le), atmospheric deposition (La):

$$L = \left(L_{agr} + L_c + L_{P1} + L_a\right), \quad (1)$$

For both cases, the point sources include the discharges of sewage waters of the industrial, agricultural and municipal enterprises. The official source of data on sewage discharges are state statistical forms ("2TPVodhoz").

The diffuse load on catchment from the emission of nutrients from various types of land surface (natural and anthropogenic) excluding agricultural areas Lc is calculated as follows:

Lc = (Cu Au + Cnat Anat + Cmix Amix) y/1000,
(2)

where Cu, Cnat and Cmix are the specific concentrations of nutrients in runoff from urban areas, the natural land surface and mixed areas, accordingly [mg l -1],

Au, Anat and Amix are the areas of the mentioned types, respectively, of a land surface [km^2], y is a runoff from the catchment [mm $year^{-1}$].

In case 1 urban areas represent the input from sparse population that is not connected to sewer networks and treatment facilities. Values of *y* from the whole catchment or its parts can be taken from measurements or calculated using distribution functions or using a hydrological model.

In case 2 nutrient load from scattered settlements was calculated using Swedish Environmental Protection Agency method, described in (Nutrient loads…, 2006). daily load per capita for N total is 13.5 g, for P total is 2.1 g.

In case 2 area type related concentrations were taken based on Swedish data provided in Kvarnäs, 1996.

Kondratyev (2007) reported that the phosphorus load from atmospheric depositions (La = da A) ranges from 0.002 to 0.005 t km^{-2} y^{-1}. Here, a value of 0.0032 t km^{-2} y^{-1} was used. Value La for nitrogen load is zero, if it is assumed that nitrogen deposition from the atmosphere (loss with deposits + fixed by biota) equals removal by denitrification (Behrendt, Dannowski, 2007).

For both cases, nutrient load generated on agricultural areas, calculated based on the method proposed by Institute of Institute for Engineering and Environmental Problems in Agricultural Production (Saint-Petersburg, Russia). It is possible to calculate loads on receiving water bodies from the particular field, farm or district. The method is fitted for North-West region of Russia conditions and based on following equation:

$$L_{agr} = \sum_{i=1}^{n_1} A_i \left(M_{soil\,i} K_1 + (\alpha_1 M_{\min i} + \alpha_2 M_{org\,i}) K_6 \right) K_2 K_3 K_4 K_5 / 1000 \quad ,$$

(3)

where M soil i , M min i and M org i – N and P content in the plough layer, as well as amount of organic and mineral fertilizer applied on field, owned by i agricultural enterprise, kg/ha;

Ai – field area, owned by i agricultural enterprise, ha; n1 – number of agricultural enterprises;

α1 – coefficient, related to the uptake of mineral fertilizer by crops;

α2 – coefficient, related to the uptake of organic fertilizer by crops;

K1 – coefficient describing nutrients outflow from plough;

K2 – coefficient describing distance of agricultural areas from receiving water bodies;;

K3 – coefficient for soils type (by origin);

K4 – coefficient describing soil texture;

K5 – coefficient for accounting land use structure;

K6 – coefficient for describing status of applying BAT for application mineral and organic fertilizer by agricultural enterprises.

Farm level calculations were performed for coastal catchments of the Gulf of Finland. For upper parts of the catchments average data by municipal districts was used.

In case 1 bckground (natural) load component [t y^{-1}] is a part of the non-point nutrient load calculated as follows:

$$Lnat = Rt\,[da\,A + yCnatA\,(1-W/100)/1000] \qquad (4)$$

where *da* – coefficient for mass exchange with atmosphere;

W – share of lake area in percentage;

Rt – retention factor.

Retention

In case 1 - for calculation of the discharge of Ptot and Ntot from the catchment and loading on water body L [tons $year^{-1}$] the following equation is used (Behrendt, Opitz, 1999):

$$L = Rt\,Ltot + Ldirect = (1-Rr)\,Ltot + Ldirect = Ltot - Lret + Ldirect, \qquad (5)$$

where Rt and Rr are dimensionless factors of discharge and retention, Ltot is the nutrient load on catchment [t y-1], Lret is the retention by catchment (Lret = Rr Ltot) [t y-1], Ldirect – direct load on water body [t y-1].

$$R_r = k_{cal}(1 - \frac{1}{1+aHL^b}), \quad (6)$$

Value of the hydraulic load HL is proportional to the specific runoff q [dm3 km^{-2} sec^{-1}] and inversely proportional to the lake percentage W [% of catchment total area]:

HL=3.15q/W. (7)

The specific runoff q [dm3 km^{-2} s^{-1}] is determined with the runoff y [mm year^{-1}] as follows

q = 0.03171 y. (8)

Transboundary inputs

Transboundary load has been defined based on shares and methods used in PLC 5.5 Project and actual monitoring data for 2017.

Uncertainty on flow, loads, unmonitored and total inputs and on sources

Uncertainty of total loads and sources has not been estimated.

References

1. BaltHazAR II project, Component 2.2: Building capacity within environmental monitoring to produce pollution load data from different sources for e.g. HELCOM pollution load compilations. Modeling the Luga river.
2. Behrendt H., Dannowski R. Nutrients and heavy metals in the Odra River System. - Weissensee Verlag Publ., Germany, 2007, 337 p.
3. Behrendt H., Opitz D. Retention of nutrients in river systems: dependence on specific runoff and hydraulic load. - Hydrobiologia, 1999, 410: 111-122.
4. Kondratyev S.A., 2007: Formirovanie vneshney nagruzki na vodoemy: problemy modelirovaniia (Formation of external loading on water bodies: problems of modeling). Nauka, St. Petersburg, 255 p, (in Russian).
5. To develop method and calculate nitrogen and phosphorous load originate from agricultural production activities in the catchment as well potential reduction when applying BAT (In Russian: Разработать методику и выполнить расчет диффузной нагрузки азота, фосфора на водосбор при ведении сельскохозяйственной

деятельности и потенциала ее снижения при использовании НДТ в сельском хозяйстве). Report about scientific and research work, IEEP RAS, 2015, 22 p.
6. To implement scientifically grounded assessment for sources appointment of nutrient input from river catchments within Russian part of the Baltic Sea catchment in 2014 (In Russian: Выполнить научно-обоснованную оценку долевого вклада всех источников в формирование в 2014 г. фактической биогенной нагрузки на водосборных бассейнах рек, впадающих в Балтийское море с российской части водосборного бассейна), Report about scientific and research work, RSHU, 2016.
7. Kvarnäs, H. 1996. Modellering av näringsämnen I Fyrisåns avrinningsområde. Källfördelning och retention. – Rapport från Fyrisåns vattenförbund 1996, 31 sid. (Modelling nutrient transport in the Fyris River catchment. Source apportionment and retention. – Report from River Fyris Water Conservation Board, Uppsala, Sweden).
8. Nutrient loads to the Swedish marine environment in 2006. https://www.naturvardsverket.se/.../978-91-620-5995-8.pdf

12. Sweden

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Calculation of flow and loads (rivers, direct point sources)

Rivers

Daily water flow and monthly concentrations (interpolated to daily concentrations) are used to calculate the monthly and annual loads for the 38 monitoring stations included in the national monitoring programme on river mouths. These monitoring stations are to some degree supported by other national and regional monitoring sites to support the estimation of loads from unmonitored areas. The monitoring stations are situated somewhat upstream to avoid saltwater intrusions (generally covering 95-100% of the catchment areas). The missing part of the monitored rivers are estimated by extrapolating the area specific loads to cover the whole catchment, which is reported to HELCOM (cf. below Unmonitored areas).

Point sources

Wastewater treatment plants (WWTP) with more than 2000 person equivalents (p.e.) and industries are monitored at the facilities on regular bases by the facility operators. As part of the authorities' control, the facility operators are obliged to report the data to the Swedish Portal for Environmental Reporting (SMP). The number of samples monitored per year may vary for different facility operators and depend on the permits given by the authorities. The facility operator reports the annual loads nationally via SMP and the data reported to Helcom are based on those reports. Fish farms also report load data to SMP. These data are typically estimated by the facility operator based on the fish feed consumption and annual growth of the fish population.

Smaller wastewater treatment plants between 200-2000 p.e. are not obliged to report their data to the authorities, therefor the loads are estimated by multiplying the number of p.e. with a coefficient that is based on the treatment technique used. The coefficient and the estimated incoming nutrient content are adjusted to Swedish conditions.

1 PE is for N=13.7 g/day and for P=1.7 g/day which is combined with a removal in the WWTP according to the table below.

Treatment method	Removal of phosphorus [%]	Removal of nitrogen [%]
Biological or soil-based treatment	35	40
Chemical treatment	88	33
Chemical and soil-based treatment	91	54
Biological and chemical treatment	92	42
Biological, chemical treatment and filtration	97	42
Biological, chemical and soil-based treatment	97	49
Biological, chemical and extra N removal	99	76

Inputs from unmonitored areas

For minor river systems that do not have any national monitoring site in the lower parts of the rivers the loads are estimated with the area-specific load from other adjacent and similar monitored rivers.

The load from unmonitored areas downstream monitoring sites are quantified by the area specific loss from the monitored parts, and the loads are included in the amounts given for the monitored areas. Generally, the monitored parts of the rivers cover some 95-100% of the total areas. Though, there are some exceptions like Rönneån where the monitoring station covers only 51 % of the total area. In addition to the area-specific load from the upper monitored area, the load from the unmonitored area is also estimated with the weighted area-specific load from other similar rivers in the area. Weighted area-specific load is used since the catchment area of the lower stretches do generally contain more farmland compared to the forested upper part of the catchment area.

Source apportionment (load and source-oriented approach)

The Source oriented approach.

The load of nutrients (nitrogen and phosphorus) to lakes and rivers has been calculated for about 39,653 subcatchments using the HYPE model. The general system approach is described in English by Brandt et al. (2009) and in Swedish by Strömqvist et al. (in prep). The load comes from point sources (WWTPs, industries, and fish farms) and from diffuse sources (land use leaching, stormwater, scattered dwellings, and the atmospheric deposition on lakes). Land use leaching (including overland flow) within a catchment is calculated by land use area (km^2) multiplied by runoff ($l/s/km^2$) and a specific concentration describing the concentration in runoff water for the current land use (mg/l). Atmospheric deposition on land surface is included in the specific concentration.

Daily mean runoff has been simulated using the HYPE model in 39,653 subcatchments for the year 2021. The load is calculated specifically for year 2021 (point source load and runoff, with data on farming, land use area, scattered dwellings and atmospheric deposition being as recent as possible).

Land use has been calculated by combining a base map (National Land Cover Database with some additions from CORINE) with crop information for agricultural parcels and reference parcels, clearcut areas, localities (continuous settlement with at least 200 inhabitants), water surface areas, and areas above 800 meters above sea level (Widén-Nilsson *et al.* in prep.).

The specific concentrations for nitrogen and phosphorus leaching from agricultural land have been calculated using the NLeCCS system (Johnsson *et al.* 2022, 2023). NLeCCS, which is a system for calculating normal leakage from arable land, includes the simulation tools SOILNDB (based on SOIL / SOILN models) for nitrogen and ICECREAMDB (based on the ICECREAM model) for phosphorus. NLeCCS system takes into account the most important factors (both farming methods and natural endowments) that affect the leaching of nutrients from agricultural land. Simulation input data include timing and amount of fertilization (both manure and mineral fertilizer), timing of sowing, harvest and ploughing, atmospheric deposition, crop yield, catch crops, buffer zones, climate data, crop rotations, crops, soil type, soil phosphorous content, and soil slope.

Leaching from forests, clear-cut forests, wetlands, alpine areas and other open land use have been calculated using the HYPE model (Lindström *et al.* 2010; Strömqvist *et al.* in prep).

Stormwater surface runoff coefficients and specific leakage concentrations of urban land use classes comes from the StormTac database[3]. The specific concentrations were geographically adjusted using weighting by the deposition rate of nitrogen.

Diffuse load from scattered dwellings was calculated using the number of inhabitants not connected to wastewater treatment plants, load per person, reduction efficiencies of treatment techniques and municipal information on the treatment techniques used.

Deposition of nitrogen on lake surfaces is based on calculations using the MATCH model[4] and assimilated data, while the deposition of phosphorus is an average value for 2019-2021 based on monitoring data.

Point source load is calculated based on direct measurements at the facility (including data reported to SMP). Load from small point sources of wastewater treatment facilities is calculated based on loads with regard to other data, such as type of treatment technology and number of persons equivalents connected and load per person.

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[3] https://data.stormtac.com/

[4] https://www.smhi.se/en/research/research-departments/meteorology/match-transport-and-chemistry-model-1.6831

The load-oriented approach.

The net load to the sea was calculated with retention modelled using the HYPE model in about 39,653 subcatchments. The total source apportioned load calculated to the river mouths was weighted to the total PLC annual river load reported in monitored and unmonitored rivers, and all sources were adjusted according to the weight.

The methodology used is based on the HYPE hydrology and water quality model which was set up for Sweden. This model differs in some way from the model used in the previous PLC reporting. The main difference is the methodology used for calculating nutrient leaching from forests, wetlands and mountainous areas. The model has been calibrated and validated on a large data set of time-series data with flow discharge and riverine concentrations of nitrogen and phosphorus. Results show that the model generally captures the spatial variability in river discharge and average nitrogen and phosphorus concentrations across Sweden (Strömqvist *et al.* in prep).

Retention

The retention from source to sea was calculated using the surface water routines in the HYPE model for all 39 653 sub-catchments. The HYPE-model (Lindström et. al. 2010; Strömqvist *et al.* in prep.) simulates the most important surface water processes affecting nitrogen and phosphorus in rivers (both the main river and smaller local rivers in sub-catchments), and in lakes and reservoirs. Internal load from the lake sediments (negative retention) was reported for lakes where the mass balance was supported by inlet to outlet monitoring data.

Transboundary inputs

Swedish catchments do not contribute to any significant transboundary output to the neighbouring countries. The load from Norwegian and Finnish catchments contributing to Swedish catchment was calculated using Corine Land Cover as land use representation with less detailed additional data on anthropogenic land use sources compared to the Swedish subcatchments. Finnish point source data for year 2021 was delivered from SYKE and Norwegian point source data for year 2020 was delivered from Miljødirektorate and included in the model. Transboundary load was reported by Sweden in PLC8 for the Finish part of Torne älv subcatchment area.

Uncertainty on flow, loads, unmonitored and total inputs and on sources

The uncertainty of sources has large variations due to the different underlying data and model performances. The uncertainty of sources has not been reported by Sweden for the PLC8 report.

References

Brandt, M., Ejhed, H. and Rapp, L., 2009. Nutrient loads to the Swedish marine environment in 2006 Sweden's Report for HELCOM's Fifth Pollution Load Compilation. https://urn.kb.se/resolve?urn=urn%3Anbn%3Ase%3Anaturvardsverket%3Adiva-9497

Johnsson, H., Mårtensson, K., Lindsjö, A., Persson, K. och Blombäck, K. (2022). NLeCCS - a system for calculating nutrient leakage from arable land. Uppsala: Sveriges lantbruksuniversitet. (Ekohydrologi, 177). https://res.slu.se/id/publ/118675

Johnsson, H., Mårtensson, K., Lindsjö, A., Persson, K., Andrist Rangel, Y. och Blombäck, K. (2023). Läckage av näringsämnen från svensk åkermark - Beräkningar av normalläckage av kväve och fosfor för 2019. Uppsala: Sveriges lantbruksuniversitet. (Ekohydrologi, 178). https://res.slu.se/id/publ/121297

Lindström, G., Pers, C.P., Rosberg, R., Strömqvist, J., Arheimer, B. 2010. Development and test of the HYPE (Hydrological Predictions for the Environment) model – A water quality model for different spatial scales. Hydrology Research 41.3-4:295-319.

Strömqvist J., Elenius M., Lindström G., Pers C., Temnerud J. (in prep). Beräkning av näringsämnestillförsel till ytvatten och retention i sjöar och vattendrag för PLC8-rapportering - Underlagsrapport till Pollution Load Compilation 8. SMED Rapport Nr 24 2022, smed.se [Report submitted for publication]

Widén-Nilsson, E. et al. (in prep). Kartdata till PLC8. SMED Rapport 2023, smed.se [Report in preparation]

Annex 1

Details on the models used by contracting parties with an overview on main in-data and out-data, resolution of these data and model resolution. Elaborated by Michal Pohl, Swedish Agency for marine water and management (SWAM), based on inputs from PLC-7 IG members.

CP	model-name	purpose	main indata				Model resolution		outdata			validation/calibration	
			type	source	temporal	spatial	temporal	spatial	**type**	**temporal resolution**	**spacial resolution**		**english documents**
Estonia	EstModel	nutrient loads, retention and source apportionment	basin and subcatchment boundaries	national database (EELIS)		vector	per year	per subcatchment	nutrient loads	per year	per subcatchment and landcover	diffuse source load and retention: calibration of nutrient loads against observations per measurement station catchment	
			land cover	Corine	6 year								
			crop type	national database (PRIA)	per year								
			soil types	national KeMIT GeoServer		1:10 000							
			drainage	national KeMIT GeoServer	per year								
			harvesting	national KeMIT GeoServer	per year				retention	per year	per subcatchment and landcover		
			fertilizer usage	expert judgement	per year								

			atmospheric deposition	observed and calculated by EKUK		nationwide							
			flow observations	national database (Estonian weather service)	per day	53 stations							
			nutrient observations	national database (KESE)	12 times per year	52 stations							
			Pointsources	national database (KOTKAS)	per quarter	for each site							
			livestock	national database (PRIA)	per year								
Finland	VEMALA (including SYKE-WSFS, ICECREAM, lake biogeochemical model, forest model)	nutrient leaching, export, retention, source apportionment	Hydrology	modelled with SYKE-WSFS	monthly-weekly	all stations	daily	catchment 4th division	nutrient concentrations, loads	daily	catchment 4th division		A National-Scale Nutrient Loading Model for Finnish Watersheds—VEMALA | SpringerLink
			Pointsources	National point load register YLVA	monthly-annual	national							
			scattered settlement load	Built environment register	annual	national							
			land use	CORINE									
			retention in lakes	modelled with VEMALA v3 lake									
			nutrient loads agricultural soils	modelled with ICECREAM									
			nutrient loads from forest soils	modelled with Non-agricultural area model									

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<tr><td>Lithuania and Poland</td><td>SWAT</td><td>source apportionment, retention and nutrient model (unmonitored areas)</td><td>atmospheric deposition (N)</td><td>national statistics</td><td>per year</td><td>nationwide</td><td>per day</td><td>HRUs (hydrological responce units)</td><td>nutrient loads</td><td>per year</td><td>per (sub-)basin</td><td></td><td>https://vanduo.gamta.lt/files/3%20priedas_SWAT%20modelis_20150817_SD.doc</td></tr>
<tr><td></td><td></td><td></td><td>basin boundaries</td><td>observed</td><td>per day</td><td>per (sub-)basin</td><td></td><td></td><td>retention</td><td>per month</td><td>per riverbranch (defined in GIS -0.2 km - 99999 km)</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>crop type</td><td>observed and extrapolated</td><td>per hour</td><td>per riverbranch</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>drainage</td><td>maps</td><td></td><td>per tile</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

			elevation	expert judgement									
			fertilizer usage	modelled									
			hydrology						runoff	per day			
			land cover	Corine					source apportionment				
			flowdata/hydrolog y										
			land use										
			lifestock-density										
			point sources										
			precipitation										
			slope										
			soil types										
			temperature										
			topography										
			yields (agricultural)										
			wind										
			humidity										
			Soil P content										
			solar radiation										
			channel width										
Poland	MIKE HYDRO Basin	river discharge	basin boundaries drainage evapotranspiration hydrology elevation precipitation temperature	expert judgement modelled observed and extrapolated query	per day	per basin per riverbranch	per day	per basin per riverbranch	river discharge in points where are no measurements	per day	per basin per riverbranch	model calibrated	MHydro_Basin_printed.book (mikepoweredbydhi.help)
Sweden	HYPE	runoff, retention, nutrient loads	precipitation and temperature	PTHBV map based on observations	daily	4 km grid	daily	hydrological response units	runoff	daily	per subcatchment and landuse	runoff: calibration	https://www.tandfonline.com/doi/full/1

		and source apportionment	sub-catchments	national SVAR database		median size ~7km2						against observations	0.1080/02626667.2011.637497
			land cover and land use	combination of maps		mixed							
			soil type/texture	combination of maps	-								
			P & N deposition	MATCH model (N) or average from observations (P)		20 km grid			retention	average	subcatchment	retention: calibration of nutrient concentrations against observations	https://iwaponline.com/hr/article/41/3-4/295/822/Development-and-testing-of-the-HYPE-Hydrological
			nutrient loads agricultural soils	modelled with NLeCCS	climate normalized	per crop and soil type (for P also for different slopes and soil P content) of 22 agricultural regions							
			nutrient load from urban land	calculation based on among others the StormTac database, a query about municipal urban water cleaning and spatial information of cities									
			dam regulations	various sources including dam operators									
			Pointsources	national registers, survey, population statistics and data on									

				treatment technique effectivity									
			Scattered dwellings	survey, population and estate statistics and data on treatment technique effectivity					nutrient loads	daily	per subcatchment and landuse		HYPE information and code: https://hypeweb.smhi.se/
			lake information	SVAR database	-	>35000 lakes							
			Flow observations	SMHI	daily	~450 stations							
			Nutrient observations	SLU national data repository	weekly-monthly	>1000 sites							
	NLeCCs	nutrient loads from agricultural land, climate normalized	nitrogen deposition	MATCH model	yearly	20 km grid	daily	field	nutrient leaching coefficients	climate normalized	per crop and soil type (for P also for different slopes and soil P content) of 22 agricultural regions	N: no calibration (uses database of earlier calibrated soil parameters)	https://pub.epsilon.slu.se/16179/7/johnsson_h_et_al_190527.pdf
			crop distribution	national statistics	year	agricultural region based on IACS field data							
			yields	national statistics based on query	normalised year	agricultural region based on yield regions							
			fertilizer input (manure and commercial)	national statistics based on query	year								
			agricultural management	national statistics based on query	year								
			climate data	observed	day based on hourly data								

			runoff	simulated with HYPE	long-term average based on daily data								
			soil types	map extrapolated from observations	-	agricultural region						P: calibration of detachment of P from observation fields	
			field sizes	IACS	year	field							
			slope	map (laser scanning)	-	sub-catchment							
			soil P content and sub-soil P content	map extrapolated from observations	-	agricultural region							
	MATCH	Nitrogen deposition	obsereved nitrogen deposition	observations					wet and dry deposition of NOx and NHx				http://www.smhi.se/en/research/research-departments/air-quality/match-transport-and-chemistry-model-1.6831
			climate data	observations						year	20 km grid		
			initial and border conditions	observations									
Germany	MoRE (Modeling of Regionalized Emissions)	calculation nutrient and pollutant emissions via pointsources and diffuse pathways to surface waters (annually) on catchment level	basin boundaries	hierarchically: small analytical units - WFD Subunits and RBD - marine catchments (Baltic Sea and North Sea)			annually	smallest resolution (analytical units) witch average size 130 km²	pathway specific emissions (point sources, diffuse pathways) for each analytical unit (nutrients and pollutants (e.g. metals, PAH, Diuron,....)	annually	pathway specific emissions for each analytical unit	using river loads for model result validation	https://isww.iwg.kit.edu/english/MoRE.php
			atmospheric deposition N	EMEP									
			atmospheric deposition P	constant value									
			land use	CORINE	2012	25 ha							
			soil types	harmonized national data set (BÜK1000)		1:1,000,000							
			elevation	NASA (2005)		100x100m							

			drainaged areas	estimation		% of agricultural land on federal state level							
			N-surplus calculated based on agricultural data (life-stock, yields, fertilization)	national statistics on NUTS3-Level	annually	NUTS3							
			UWWTP	UWWTD-data (Plants > 2,000 p.e.) and statistical information for plants < 2,000 p.e. and scattered dwellings	UWWTD-circle (every two years)	> 2,000 p.e. on point source level, < 2,000 p.e. on LAU1/LAU2 level							
			Industries	PRTR	yearly	facility level							
			meteorological data (precipitation, temperature, etc.)	national data set (DWD)									
			water quality data (for model calibration)	national data set (federal state data)									
			flow (for hydrology)	national data set (federal state data)									
			erosion (USLE)	divers input data to calculate single USLE factors									
			soil content P	data from federal states		varying (depending on data availability in federal states)							

Russian Federation	Institute of Limnology Load Model (ILLM)	source apportionment and retention & nutrient model (unmonitored areas)	land cover and land use	geospatial data from satellite imagery	-	per sq.km	annually	per sub-basin	nutrient loads	per year	per riverbranch (defined in GIS -0.2 km - 99999 km)	modelled data against direct measurements	Appendix 3a. BaltHazAR II project, Component 2.2: Building capacity within environmental monitoring to produce pollution load data from different sources for e.g. HELCOM pollution load compilations. Modelling the Luga river. http://helcom.ru/media/Annex%203a_eng.PDF
			input from agriculture	modelled by IEEP model	per year	per municipal district within sub-basin							
			retention coefficients	results of the earlier studies (from articles etc.)	per year	per basin			retention	per year	per riverbranch (defined in GIS -0.2 km - 99999 km)		
			point sources input	statistical data available by query in aggregated form	per year	per sub-basins			source apportionment	per year	per riverbranch (defined in GIS -0.2 km - 99999 km)		
			run-off	direct measurements data	per year	per month							
			leaching coefficients for different land cover/use (except agriculture lands)	results of the earlier studies (from articles etc.)	constant	per basin							
	IEEP model	N and P losses from agriculture (fields)	amount of organic fertilizer applied on field	official statistical data	per year	per municipal district within sub-basin	anually	per field/municipal district/basin	N and P loss to water via surface and subsurface runoff	per year	per riverbranch (defined in GIS -0.2 km - 99999 km)	calibration included during ILLM model run only (above)	https://www.researchgate.net/publication/323802151_CONTRIBUTION_OF_AGRICULTURAL_SOURCES_TO_NUTRIENT_LOAD_GENERATED_ON_THE_RUSSIAN_PART_OF_THE_BALTIC_SEA_CATCHMENT_AREA
			amount of mineral fertilizer applied on field	official statistical data	per year	per municipal district within sub-basin							
			soil type/texture	soil maps	-	per sub-basins							
			crop type	official statistical data	per year	per municipal district							

						within sub-basin							
			topography (distance to receiving watercourse)	land use maps from satellite	-	per sq.km							
Denmark	DK-QNP (the Q is obtained from national water resources model (DK-model) below	Estimating Nutrient load (TN, TP), retention, source apportionment					monthly	ID15	Nitrogen load/runoff	Monthly Year	ID15-subcatchment Subbasin National	Calibration against observations	
			Nitrogen surplus		Year	National							
			Precipitation	DMI	monthly	10X10km grid							
			Temperature	DMI	monthly	20x20 km grid							
			Landuse	National Field repository	year	Field							
			Drainage percentage	National Soil repository									
			soiltype	National Soil repository									
			Subcatchments	DCE subcatchment-data repository		Mean size 15 km2							
			Flow observations	ODA DCE-national surfacewater data repository	daily	250 sites							
			Nutrient observations	ODA DCE-national surfacewater data repository	Monthly	250 sites							
			Nutrient load Aquaculture	PULS national data repository	year								
			Nutrient load Industries	PULS national data repository	year								

			Nutrient load waste water treatmentplant >30PE	PULS national data repository	Year								
			Nutrient load storm-water outlets	PULS national data repository	Year								
			Nutrient load scattered dwellings	National building repository	Year								
			Retention lakes	Retention model	year								
			Retention streams	Expert judgement	year								
			Retention constructed wetlands	Expert judgement	year								
			Flow unmeasured catchment	GEUS : DK-Model (National Water resource model)	Monthly								
	National water resources model (DK-model)	Modelling of water resources in Denmark	Precipitation	DMI	daily	10X10km grid	daily	500x500	groundwater head	daily	500x500m	calibration on disharge and groundwater head 2000-2010, split-sample validation 1990-2000 + 2010-2020 (discharge and gw head). Optimisation of multi object function using gradient based methods (PEST)	https://doi.org/10.1016/j.envsoft.2012.09.010
			temperature	DMI	daily	20x20km grid							
			potential evaporation	DMI	daily	20x20km grid							
			crop distribution	national statistics	stationary	100x100m grid							
			topsoil types	AAU - DCA	stationary	250x250m grid							
			topsoil lithology	GEUS	stationary	1 to 25.000			streamflow discharge	daily	appr. 45.000 stations		
			Hydrogeology in 3D	GEUS	stationary	100x100m grids							
			bathymetry	national gis database	stationary	100x100m grid							

			abstraction	GEUS / national well database	year	station (well field)							
			waster water discharge	national gis database	year	station							
			landuse classification	AAU	stationary	10x10m grid			various water balance variables	daily	500x500m		https://doi.org/10.1016/S0022-1694(03)00186-0
			river cross sections	counties / GEUS	stationary	station							
			stream discharge	AAU / national gis database	daily	station							
			groundwater head observations	GEUS / national well database	varying (hour-yearly)	station (well intake)							
Latvia	EXCEL-based calculations	estimation of nutrient retention and source apportionment	nutrient loads	LEGMC	year	13 stations	yearly	catchment	retention	year	catchment	estimated values checked against the observed loads	
			flow	LEGMC	year	10 stations			source apportionment	year	catchment		
			subcatchment area	LEGMC									
			area of surface water	Corine	2012	catchment							
			land use types	Corine	2012	catchment							
			nutrient export coefficients	results of the earlier studies									
			retention of transboundary loads	PLC-Water guidelines		catchment							
			point source loads	2-Ūdens national databse	year								