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Swedish National Nitrogen Budget - Hydrosphere

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Summary

Excessive amounts of reactive nitrogen (Nr) in the hydrosphere can impair water quality and alter the functioning of aquatic ecosystems. Monitoring of water bodies and awareness of the existing flows of nitrogen from different sectors in society can support policy making. In this report we quantified the major flows of Nr in the Hydrosphere pool of the Swedish National Nitrogen Budget, according to the methodology provided by the Task Force on Reactive Nitrogen. Calculations were done for one full year using data mainly from 2014 but also from 2015.

In 2014/2015, the largest inflows of Nr to the Swedish hydrosphere were leaching from agriculture (53 kilotonnes, kt), from forests (48 kt), atmospheric deposition (33 kt), leaching from wetlands and other land (20 kt) and municipal wastewater treatment plants (17 kt). In addition, there were minor contributions from industrial wastewaters, small dwellings and from stormwater runoff. The major outflows were transport from the coastal waters to the open sea and marine denitrification (together 127 kt) and denitrification from freshwaters (34 kt) N. In addition, there were quantitatively less important Nr losses through fishing, N_2O emissions and water abstraction.

Most of the data in this report originate from the Swedish reporting to the Helcom ”Pollution Load Compilation 6 - PLC6” in which Sweden's nitrogen and phosphorus flows have been estimated for year 2014. The work with the PLC6-report was carried out within Svenska MiljöEmissionsData (SMED consortium). Other data sources are Statistics Sweden (fisheries data), Nationellt vattentäktsarkiv (surface water concentrations) and SMHI (atmospheric deposition).

Sammanfattning

Ett överskott av reaktivt kväve (Nr) i hydrosfären kan påverka vattenkvaliteten negativt och förändra de akvatiska ekosystemen. Övervakning av vattendrag, sjöar och kustvatten och kunskap om flödet av kväve mellan olika sektorer i samhället kan ge stöd i beslutsfattande och förvaltning. I denna rapport uppskattades de huvudsakliga flödena av Nr från Hydrosfärs-poolen i Sveriges nationella kvävebudget under ett år, enligt metodiken från Task Force on Reactive Nitrogen, med data huvudsakligen från 2014, men för vissa flöden för 2015.

Under 2014/2015 var de huvudsakliga källorna till reaktivt kväve i den svenska hydrosfären avrinning och läckage från jordbruksmark (53 kiloton, kt), skogsmark (48 kt) och våtmark och annan mark (20 kt) samt utsläpp från avloppsreningsverk (17 kt). Därutöver förekom mindre inflöden av Nr från industriellt avloppsvatten, vatten från små avlopp och dagvatten. De största utflödena av Nr utgjordes av transport av kustvatten till omgivande hav och denitrifikation i kustzonen (tillsammans 127 kt) och denitrifikation i sötvatten (34 kt). Därtill skedde mindre utflöden av Nr genom fiske, N_2O emission och vattenuttag.

Stora delar av den data som används i denna rapport kommer från Sveriges rapportering till Helcom ”Pollution Load Compilation 6 – PLC6” i vilken Sveriges kväve- och fosforflöden har sammanställts för år 2014. Arbetet med PLC6-rapporten utfördes inom konsortiet SMED (Svenska MiljöEmissionsData). Andra datakällor har varit Statistikmyndigheten SCB (fiskeridata), Nationellt vattentäktsarkiv (ytvattenkoncentrationer) och SMHI (atmosfärsdeposition)

Introduction

The Task Force on Reactive Nitrogen (TFRN) was established under the Working Group on Strategies and Review (WGSR) by the Executive Body at its twenty-fifth session in December 2007.

The purpose of TFRN has been defined as: *"The Task Force will develop in the long-term technical and scientific information and options which can be used for strategy development across the UNECE to encourage coordination of air pollution policies on nitrogen in the context of the nitrogen cycle and which may be used by other bodies outside the Convention in consideration of other control measures."* For the full terms of reference of the Task Force, see Executive Body decision 2007/1.

At the first meeting (Wageningen, 2008), TFRN agreed to define reactive nitrogen (Nr) as all biologically active, photochemically reactive and radiatively active N compounds in the biosphere and atmosphere, for example, nitric oxides, nitrogen dioxide, nitrate (NO_3^-), organic N compounds, nitrous oxide (N_2O), ammonia (NH_3) and ammonium (NH_4^+). This meant, in practice, all N except for nitrogen gas (N_2). At the same meeting it was proposed that an expert panel could help in preparing for the reporting of national budgets, first exploring methodologies and providing a reference template for the compilation. The Expert Panel on Nitrogen Budgets (EPNB) was established (first as an ad-hoc group) and commenced work to prepare guidelines for compilations of national N budgets of individual countries. EPNB prepared the "Guidance Document on National Nitrogen Budgets". The document was presented and approved at the 31st meeting of the Executive Body of the Convention on Long-Range Transboundary Air Pollution in December 2012. The document can be downloaded from http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/ECE_EB.AIR_119_ENG.pdf. After that the work of EPNB continued to provide detailed guidelines for each of the 8 main parts of the National N Budget (NNB) summarised in Annexes to the ECE/EB.AIR/119 – "Guidance document on national nitrogen budgets". Currently the version dated 21. 09. 2016 is available at http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20160921_public.pdf and it summaries six out of the eight pools. As of September 17, 2019, also the "Energy and fuels" Annex has been made available (http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_1_EF_190913.pdf). Annex 5 Waste is still under development.

There have been attempts constructing nitrogen budgets in some of the European countries and elsewhere, see for example Switzerland (Heldstab et al., 2010 and 2013), Germany (Geupel et al., 2009), Denmark (Hutchings et al., 2014) or Canada (Clair et al., 2014). These budgets have not followed the same protocol when constructed but provide information on important flows. Bach et al. (UBA 2020) used the TFRN Guidance document and compiled a NNB for Germany which includes all 8 pools described in the document. In Europe, Sutton et al. (2011) estimated that 74% of the total input of reactive nitrogen to the environment stems from the Haber-Bosch process, in which reactive nitrogen is industrially produced, 16% from combustion, and the remaining 10% from biological fixation, import of feed and products. Leip et al. (2011) estimated nitrogen fluxes for EU27, developing and using the same protocol for all countries. Among the key findings was that the largest single sink for reactive N appears to be denitrification to N_2 in European coastal shelf regions (potentially as large as 11 000 kt N yr^{-1} for the EU-27) with the caveat that this is one of the most uncertain sinks due to the uncertainties of Nr import from the open ocean. Leip et al. (2011) recommend development of nitrogen budgets nationwide, since the assessment and management of the budgets could become an effective tool to prioritize measures and prevent unwanted effects.

National nitrogen budgets (NNB) following the EPNB methodology are constructed based on eight pools (Figure 1). In a previous report on the agriculture pool of the Swedish NNB (Stadmark et al. 2019) year 2015 was chosen since that year was the most recent year with available statistics. In this report, where data on pool 8 (Hydrosphere) is presented, we therefore use year 2015 when data is available, and year 2014 if no compiled data from 2015 is available. The data presented in this report consist of data reported to HELCOM in the PLC6 report (Ejhed et al., 2016) or are calculations based on data from Swedish agencies and reports. These data are regularly updated, and PLC reports are so far produced every 3-5 years by the SMED-consortium, which is convenient for future updates of the Swedish NNB.

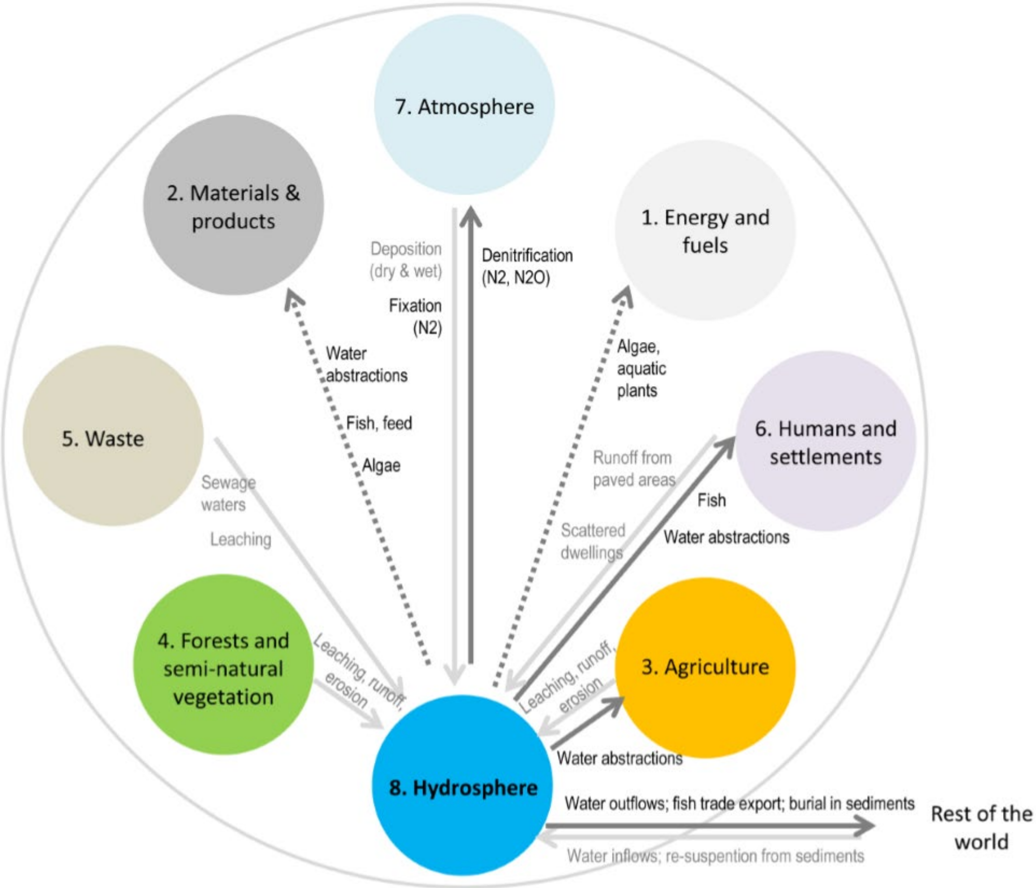

Figure 1. Nitrogen flows between the Hydrosphere and the other pools of the National Nitrogen Budget (including the pool “Rest of the world”). Light grey arrows represent nitrogen flows entering the Hydrosphere from the other pools; dark grey arrows show nitrogen flows from the Hydrosphere to the other pools. Dotted arrows indicate that (parts of) these nitrogen flows are not quantified in the present document. (Figure adapted from: http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20160921_public.pdf)

National nitrogen budget (NNB) for Hydrosphere (pool 8)

The EPNB methodology divides the Hydrosphere pool into three compartments; surface water, groundwater and coastal water. In this report we focus primarily on the exchanges of Nr that occur between the Hydrosphere pool and other pools in the Swedish NNB and do not aim to disentangle the internal flows within the Hydrosphere entirely.

A large proportion of the nitrogen that is emitted to surface waters is eventually ending up in the coastal waters. In PLC6, with data from 2014, 115 kilotonnes (kt) of N reached the sea. 149 kt were emitted to inland waters and 10 kt emitted to the coastal seas directly. The Nr which enters the coastal waters could leave to the outer sea, could be denitrified or could gradually increase the Nr concentration in the water and the size of the coastal water sub-pool (CW). In theory, there could also be an inflow of Nr from the outer sea to the CW. Removal of Nr through fishing is in this context of minor quantitative importance. In this report, we were unable to find a quantification of the Nr flow between CW and outer sea or reliable estimates of marine denitrification. To quantify the annual accumulation of Nr in CW is also a question beyond this work. Therefore we assumed that the size of the CW pool is not changing and that the Nr which enters the CW (less the amount of N extracted through fishing and N_2O emissions) is lost to the Rest of the World, either through denitrification as N_2 emissions or as Nr in the water transported to the outer sea, see further discussion below.

All flows, indicated with arrows in Figure 2, are described below and briefly described in the following sections.

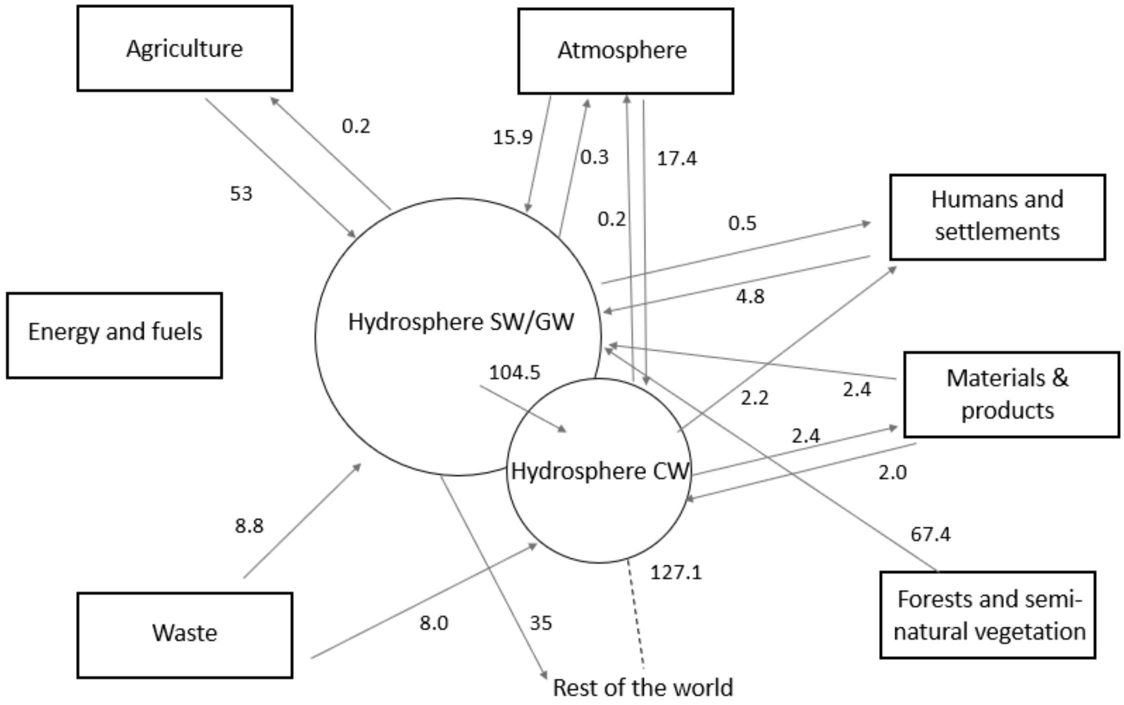

Figure 2. Flows of nitrogen between the Hydrosphere pool and the other pools in the Swedish national nitrogen budget, in kilotonnes (kt). SW/GW = surface water/groundwater, CW = coastal water. The dashed line from Hydrosphere CW to Rest of the World indicates a potential flow, but parts of this Nr could also remain in the coastal waters and contribute to an increased pool of Nr there.

Forests and semi-natural vegetation - Hydrosphere

More than 70% of Sweden is covered with forests, wetlands and other lands and these areas therefore contribute with large quantities of reactive nitrogen to the hydrosphere. The runoff of nitrogen from forest areas to the Hydrosphere was 47.8 kt in 2014 (Ejhed et al. 2016, Table 10) and from wetlands and other lands 19.6 kt (Ejhed et al. 2016, Table 10). The transport of reactive nitrogen between two individual pools is largest between the pools Forest and semi-natural vegetation and Hydrosphere. Much of the Nr transport from Forest and semi-natural vegetation is Nr in organic form (dissolved organic nitrogen, DON) which in Sweden is typically much larger than the transport of Nr in inorganic forms in forest areas. Leaching of DON is strongly correlated with leaching of dissolved organic matter (DOM). DOM consists of soluble organic materials derived from the partial decomposition of organic materials, including soil organic matter, plant residues, and soluble particles released by living organisms, including bacteria, algae, and plants. All the components of DOM contain N and the DON leaching is to a large extent a natural process.

Agriculture - Hydrosphere

Runoff and leaching from agricultural land to the hydrosphere was 53 kt (according to the National Nitrogen Budget for Agriculture for 2015) which is the same range as the 50.2 kt that was estimated in the PLC6-report. The Agriculture pool includes aquaculture, which amounts to approximately 0.5 kt N per year.

The total freshwater abstraction in Sweden was 2 443 910 000 m^3 in 2015[1]. Out of this, approximately 900 000 000 m^3 is for drinking water production. The rest is for irrigation and water for industrial use. In this report all the remaining water (1 544 000 000 m^3), with an average content of 0.11 mg N l^{-1} (data from the Swedish Geological Survey's Vattentäktsarkiv, with data collected in the "Nationell miljöövervakning och regional miljöövervakningsdata", funded by the Swedish Agency for Marine and Water Management), in total 0.17 kt, is allocated to the Agriculture pool.

Atmosphere - Hydrosphere

Deposition of reactive nitrogen directly to water surfaces of lakes, streams and coastal areas in 2015 was estimated to 33.3 kt (Moldan et al., in prep.) and 15.9 kt in 2014 (Ejhed et al. 2016). The latter estimate does not include deposition on coastal waters and streams. In this report the deposition directly on coastal waters is estimated to be 17.4 kt, based on the difference between the two numbers above. This estimate is rough since data comes from two different years and the deposition on streams might be underestimated.

The removal of nitrogen from the surface waters, mainly through denitrification, was estimated to be 30 kt per year in Sweden (Arheimer and Pers, 2007) which corresponds well with the retention of 35 kt of nitrogen in PLC6 (Ejhed et al. 2016). Nitrogen gas (N_2) is considered to go to the pool Rest of the world since it is no longer reactive nitrogen. Approximately 1% of the denitrified nitrogen enters the atmosphere as N_2O (Seitzinger and Kroeze 1998, IPCC 2019). Ejhed et al. (2016) estimated the inflow from land to all Swedish coastal waters to 114.6 kt and Asmala et al. (2017) estimated the nitrogen removal in the coastal zone of the Baltic Sea to 16% of the nitrogen inflow from land. If all this removal is due to denitrification with 1% emitted as N_2O it gives 0.2 kt reactive nitrogen to the Atmosphere and 18.1 kt N_2 to the Rest of the World. If Nr deposited on coastal waters is denitrified to the same extent as the inflowing water it would contribute with a minor emission of N_2O (0.03 kt) to the atmosphere and 2.8 kt transferred to the Rest of the World as N_2. In this budget we did not include denitrification of deposited Nr to N_2 in the denitrification bars in Figures 4 and 5. The total emission of reactive nitrogen to the Atmosphere is estimated to 0.5 kt.

To our best knowledge nitrogen fixation in waters, by e.g. cyanobacteria, has not been quantified for Sweden by any existing study and it has not been estimated in this report.

Waste – Hydrosphere

The effluents from wastewater treatment plants to surface waters and coastal waters contained 8.8 and 8.0 kt of N respectively in 2014 (Table 11, PLC6).

Runoff from landfills is included in the calculations of runoff from industrial areas and cannot be reported separately.

[1] https://www.scb.se/hitta-statistik/statistik-efter-amne/miljo/vattenanvandning/vattenuttag-och-vattenanvandning-i-sverige/pong/tabell-och-diagram/vattenuttag-2015-efter-typ-av-vatten-per-vattendistrikt/

Humans and settlements - Hydrosphere

Small dwellings contributed with 3.1 kt of N to the hydrosphere in 2014 according to PLC6 (Ejhed et al. 2016, Table 10). Runoff from paved areas (stormwater) were estimated to contain 1.7 kt of N (Table 10, PLC6) in 2014.

Data on fish catch is closely monitored and published annually by Statistics Sweden. In Swedish freshwaters around 15% of the catch is from commercial fishing[2] and 85% from recreational fishing[3]). The total nitrogen content of the harvested fish amounted to 0.3 kt of N in 2015. In coastal waters and other fish harvested by the Swedish commercial fishermen (93%)[4], and recreational fishers (7%)[5], contained 2.2 kt of N. These calculations are based on the protein content of fish and crayfish and the conversion factor from protein to nitrogen used by the Swedish Food Agency[6]. The amounts are not including the fish for feed, since that flow in this national nitrogen budget goes from Hydrosphere to Materials & products (see below).

Water abstraction for drinking water production is estimated to contain 0.2 kt N per year, based on an average nitrogen concentration of 0.23 mg l^{-1} (data from the Swedish Geological Survey's Vattentäktsarkiv, with data collected in the Nationell miljöövervakning och regional miljöövervakningsdata, funded by the Swedish Agency for Marine and Water Management) and an annual production of 900 000 000 m^3 in Sweden[7].

Materials & products – Hydrosphere

Fish harvested for feed by Swedish commercial fishermen in 2015 contained 2.4 kt of N based on the calculations used above (section Humans and settlements – Hydrosphere).

Wastewater from industries contained 4.4 kt of N in 2014 (Ejhed et al. 2016) (PLC6), 2.4 kt of N were emitted to the inland waters and 2.0 kt directly to the coastal waters.

Energy and fuels – Hydrosphere

Harvest of algae and aquatic plants for energy production is a suggested flow in the annex, but there is no regular harvest of e.g. beachcast for energy purposes in Sweden and no data on this has been compiled. There are therefore no direct flows between the Energy and fuels pool and the Hydrosphere pool in this report.

Rest of the world - Hydrosphere

The contribution from catchments in Norway and Finland that are drained by Swedish streams are included in the PLC6 calculations. These catchments are only few, primarily the Finnish part of the Torne River catchment and catchments in Norway that are headwaters for the river Klarälven.

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[2] https://www.scb.se/contentassets/3726215fa1ae44a7b4b4a65fc866ad8f/jo1102_2015a01_sm_jo56sm1601.pdf
[3] https://www.scb.se/contentassets/6eaa679f076f4244a8db2bba24e4ad9c/jo1104_2015a01_sm_jo57sm1701.pdf
[4] http://share.scb.se/OV9997/data/JO1101_2015M12_SM_JO50SM1602.pdf
[5] https://www.scb.se/contentassets/6eaa679f076f4244a8db2bba24e4ad9c/jo1104_2015a01_sm_jo57sm1701.pdf
[6] https://www.livsmedelsverket.se/livsmedel-och-innehall/naringsamne/livsmedelsdatabasen?AspxAutoDetectCookieSupport=1, https://www.livsmedelsverket.se/livsmedel-och-innehall/naringsamne/protein
[7] https://www.svensktvatten.se/fakta-om-vatten/dricksvattenfakta/produktion-av-dricksvatten/

In this budget denitrification of surface water inflows in the coastal areas is accounted for, but not the inflow and outflow of Nr from and to outer sea and the inflow from the atmosphere. The estimated 114.4 kt N that is exported to the Rest of the World pool may therefore also stay in the Hydrosphere in for example coastal areas. If that is the case it should not be considered as an outflow from the Hydrosphere pool. We acknowledge that the concentration of reactive nitrogen has increased in coastal waters since the mid-20th century, but also that current efforts to decrease the emissions from land to sea has been successful. In this NNB all Swedish emissions to the Swedish territorial waters are assumed to leave to the Rest of the World and we assume no change in the N concentrations of the coastal waters in 2014/2015.

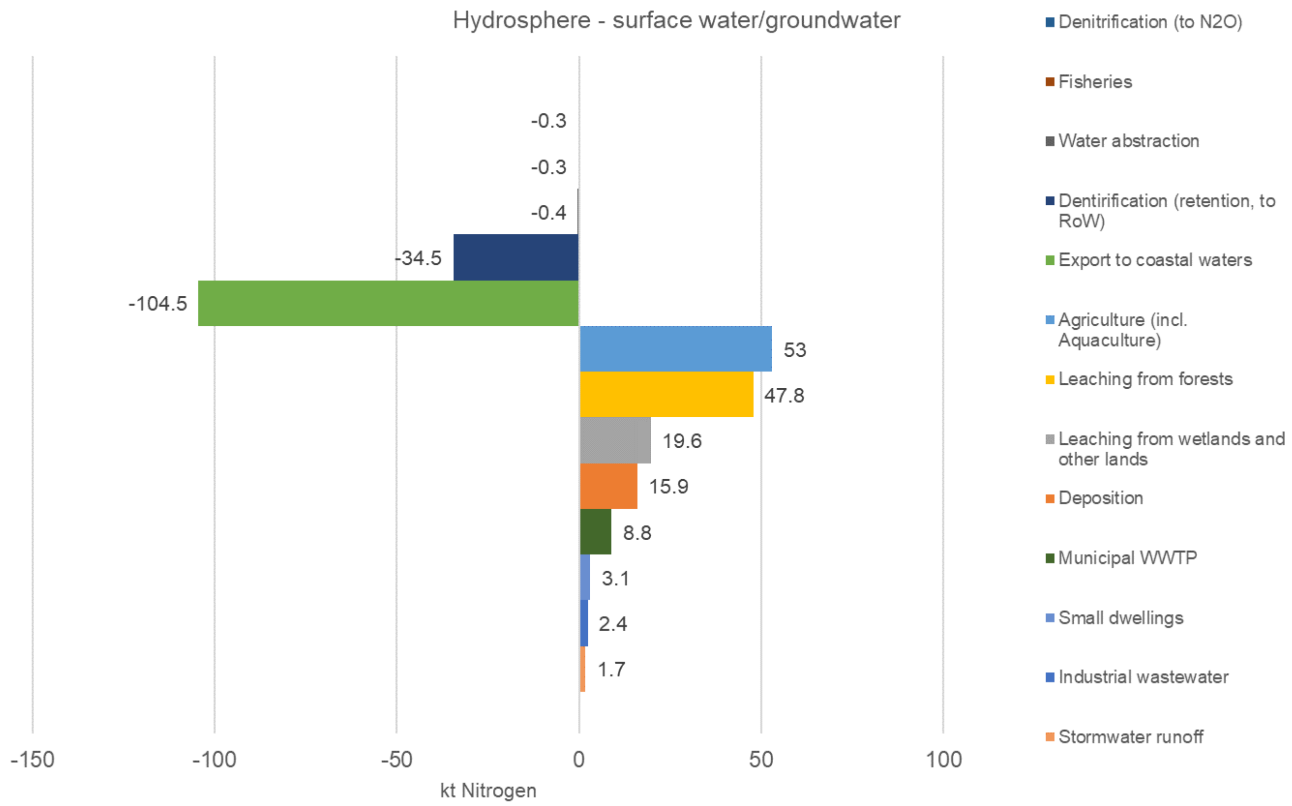

Figure 3. Inflows (152 kt) and outflows (140 kt) of Nr for the Hydrosphere – surface water/groundwater. This budget would suggest an increase in the pool of reactive nitrogen in surface waters and groundwaters. However, the imbalance by 12 kt (8%) is not large given the uncertainty in the estimates of several of the partial flows.

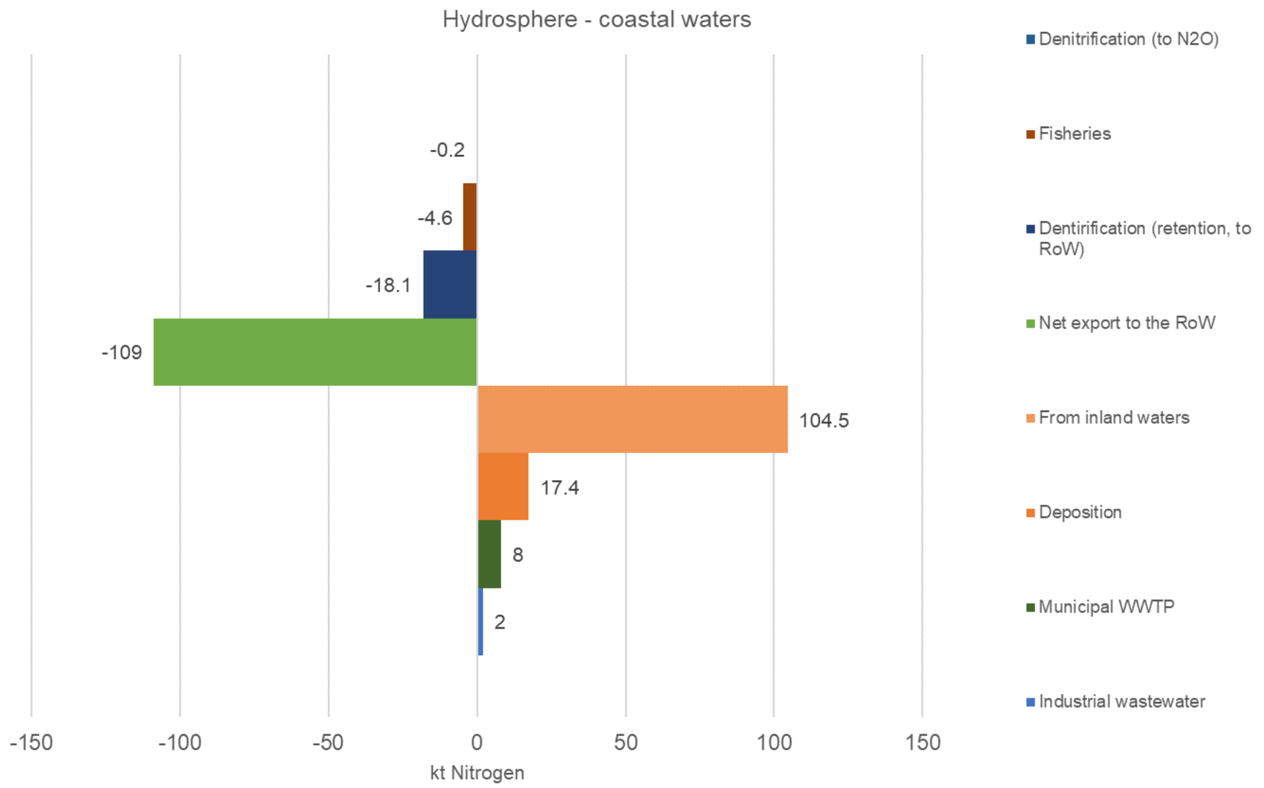

Figure 4. The inflows (132 kt) and outflows (132 kt) of Nr for the Hydrosphere – coastal waters. The net export to the Rest of the World (RoW) is estimated to balance the outflows with the inflows, which might be an overestimation of the outflows. Parts of the Nr that reach coastal waters might contribute to an increase in the reactive nitrogen pool in coastal waters.

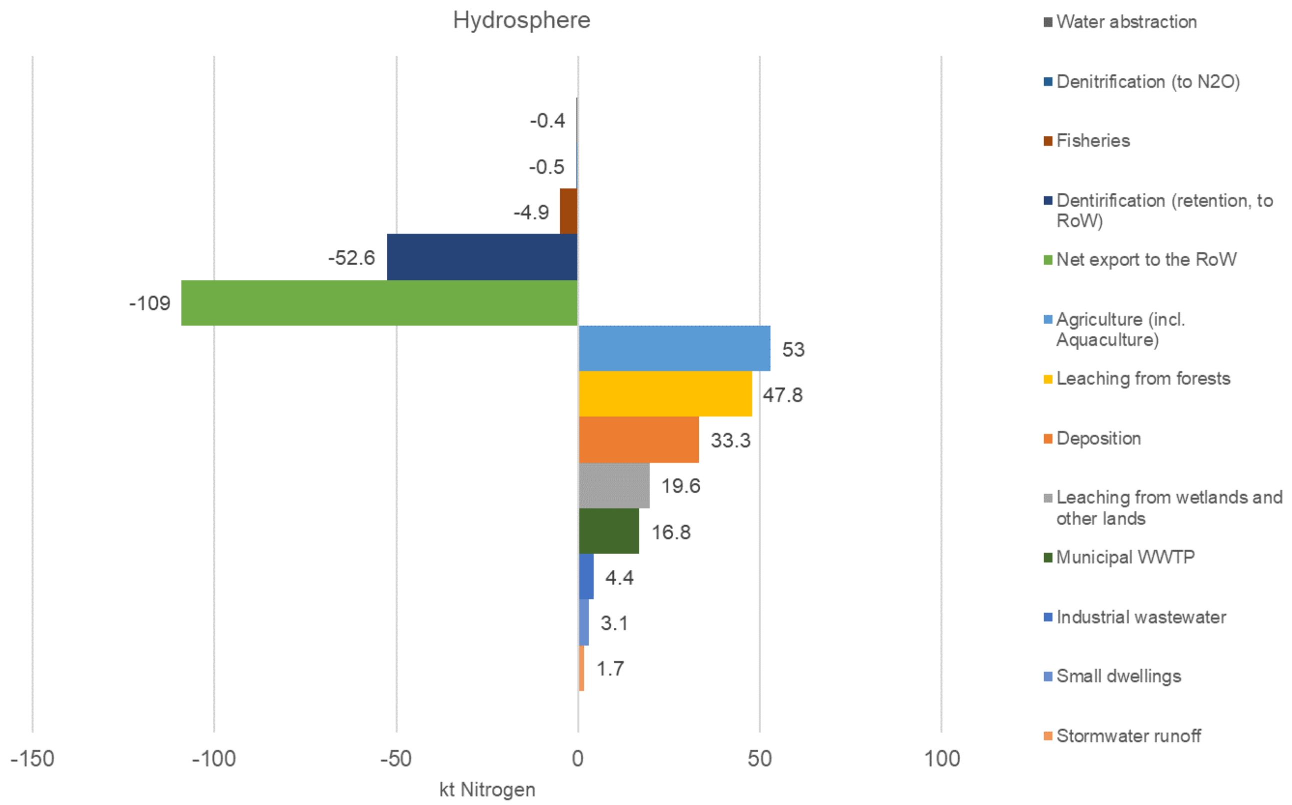

Figure 5. The flows related to the Hydrosphere pool in the Swedish national nitrogen budget. This budget assumes that all reactive nitrogen that reaches the coastal waters (though inflow from inland waters of via deposition) is transported to the Rest of the World, i.e. it does not contribute to an increase of the pool of reactive nitrogen in coastal waters.

Conclusion

In this part of the NNB for Sweden the flows connected to the hydrosphere has been surveyed. The major sources of reactive nitrogen to the Swedish hydrosphere are runoff from agriculture, forest or other land and inputs from wastewater treatment plants A large proportion of the nitrogen entering the hydrosphere is transported to the surrounding seas or removed from the hydrosphere, e.g. through denitrification. Harvest of fish from inland waters and from seas and water abstraction for drinking water or irrigation contribute with minor flows from the Swedish hydrosphere.

Inflows of Nr to inland waters are estimated to be 152 kt for one year (2014/1015) and the outflows from inland waters to the coastal waters and to the other pools in the NNB are in the order of 140 kt (Figure 3). The coastal waters are in this NNB estimated to be balanced with 132 kt of inflows and outflows (Figure 4). The entire Swedish hydrosphere (Figure 5) has inflows of 180 kt Nr and estimated outflows of 167 kt. Currently it is not possible to close the nitrogen budget of the Hydrosphere and some aspects still need to be developed or improved. For instance, the estimates of the two largest outflows of Nr from Hydrosphere (export from Swedish coastal waters to open sea and denitrification) are both associated with uncertainties.

A large proportion of the data originates from the Swedish report to HELCOM's sixth pollution load compilation with data from 2014. The pollution load compilation is carried out regularly and the data summarizes most of the Swedish flows of nitrogen (and phosphorus) to the surrounding seas. Retention of nutrients is also estimated. The consortium SMED (Svensk MiljöEmissionsData) consisting of experts from Sweden Statistics, Swedish University of Agricultural Sciences (SLU), Swedish Meteorological and Hydrological Institute (SMHI) and IVL Swedish Environmental Research Institute, processes the data on the request of the Swedish Agency for Marine and Water Management. In a previous report on the Agriculture pool of the Swedish national nitrogen budget (Stadmark et al. 2019) year 2015 was chosen since that year was the most recent year with available statistics. In this report we therefore primarily use year 2015, and year 2014 if no compiled data from 2015 is available.

Quantifying nitrogen flows into and from the water system is extremely relevant for monitoring purposes and for raising awareness on unaccounted nitrogen flows, since the excess of nitrogen can impair the quality of water resources and change the functioning of aquatic ecosystems[8]. It is difficult to assess the flows from the sea (Rest of the World) to the coastal waters and the other way around, while the major flows on land are covered in this report. Parts of the discrepancy between inputs and outputs might also be due to the two different years used.

Acknowledgment

This work was supported by Swedish Environmental Protection Agency in research program SCAC2 (Swedish Clean Air & Climate Research Program, www.scac.se) and by research grant Nr 501-19-005 "Deltagande i ICP M&M, JEG DM och TRFN 2019". We want to express our gratitude to the Swedish EPA, the Swedish Agency for Marine and Water Management, Statistics Sweden and other government agencies who support the monitoring and data collection which makes the compilation of national nitrogen budget possible. Furthermore, we would like to thank Anna Engleryd, Salar Valinia and Ulla Bertills, all at the Swedish EPA, for their long-term commitment and support for the work related to the Convention on Long Range Transboundary Pollution, including this study.

[8] http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20160921_public.pdf

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