> Nitrogen fluxes in Switzerland

A material flux analysis for the year 2005

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> Foreword

There are various reactive nitrogen compounds that are of central importance in the environment. Large quantities of nitrogen compounds are released as a result of human activity. Through natural and technical transformation processes, the physical and chemical properties of these compounds, and thereby their effects on the environment, are dramatically changed. The effects depend on which aspect of the environment is being considered: while, for example, ammonium salts have a beneficial effect when used as nutrients on agricultural land, the same effect in water courses is undesirable as here it contributes to over-fertilization.

In this study, the most relevant nitrogen compound fluxes between the different parts of the environment are identified and quantified. A similar study was carried out in 1994. In contrast to the earlier version, the methodology "Material flux analysis Switzerland" has been used here. New nitrogen fluxes were incorporated in the analysis and the data brought up to date. The results presented in this report describe not only the situation in 2005 but also give a comparison to the situation in 1994. The data from the earlier study have been converted and are presented in the same format as data from the new methodology. In selected, particularly relevant cases, a profile of the period 1994 to 2005 is shown and the changes interpreted.

Between 1994 and 2005, there were important nitrogen fluxes that declined. Emissions of nitrogen oxides from combustion and transport were almost halved. In addition, application of farm manure on agricultural soils, mineral fertilizer inputs and emissions from livestock into the atmosphere all decreased. Nitrogen emissions from waste-water treatment plants also declined, due to a targeted reduction programme. However, selected relevant nitrogen fluxes such as animal feed imports increased over the same period.

It can be expected that there will be further changes in nitrogen fluxes in the future, due, for example, to the increase use of biomass for energy production. The nitrogen balance of the subsystems Agriculture and Forestry, Production/Utilisation of Goods, Environment, and Waste Management for the year 2005 therefore serves as a benchmark for further work.

In preparing this publication we were able to draw on the expertise and collaboration of various departments and persons. We would like to give a warm thank you to those who assisted; namely, Agroscope Reckenholz, ETH and Eawag for the provision of data and information on material fluxes in agriculture and hydrology. In addition, we would like to thank the numerous resource persons from cantonal offices, advisory offices, industry and commerce who provided assistance.

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> Summary

Current situation

Current situation

Nitrogen, with all its diverse forms and thanks to its function as a nutrient, is a key element in the organic natural world. It is the essential building block for the production of protein and therefore essential for our nutrition. However, with all the developments in transport, industry, housing and agriculture in the last decades, humankind has caused large amounts of reactive nitrogen compounds to be emitted into the air, soil and water, resulting in considerable concentration disturbances in the environment. The emission of nitrogen compounds such as ammonia/ammonium (NH_3/NH_4^+), nitrogen monoxide and dioxide (NO, NO_2), etc. into the environment is harmful to people, animals and plants, and their symbiotic communities. Nitrous oxide (N_2O, laughing gas) and nitrogen trifluoride (NF_3) are strong greenhouse gases and contribute to global warming. Nitrate (NO_3^-) – a plant nutrient – is toxic to humans and contributes to the over-fertilization of surface waters, including shallow seas (North Sea).

In 1993 the nitrogen cycle in Switzerland was analysed for the first time by the Federal Water Protection Commission. As a result the “Project Group Nitrogen Cycle Switzerland”, jointly established by the federal departments for Home Affairs and for Economic Affairs, developed an overview of the nitrogen balance in Switzerland for 1994 and a strategy to reduce nitrogen emissions in Switzerland. The suggested measures were implemented in part, through agricultural and environmental policy. Although nitrogenous air pollutants from transport, industry and households were effectively reduced, the same degree of success has not been achieved in mitigating the nitrogen problem in agriculture. Switzerland is still far from reaching this goal.

This report describes the nitrogen fluxes in Switzerland for the reference year 2005. Further, it shows the development trends that have taken place since the last investigation in 1994. It serves as a scientific basis for updating the nitrogen strategy and for planning future measures. The report is designed to be used by decision makers, agriculture and environment specialists in both the public administration and the private sector, as well as tertiary institutes engaged, in a broad sense, with the subject of nitrogen.

The problem of excess nitrogen and its effects on the environment has both national and international significance. Within the framework of international conventions (Geneva Convention (CLRTAP)/Gothenburg Protocol, Kyoto Protocol (laughing gas, nitrogen oxides), OSPAR Convention, International Conference for the Protection of the North Sea (INK), the countries bordering the North Sea and the International Commission for the Protection of the Rhine (ICPR) and the International Commission for the Protection of Lake Constance (IGKB)) Switzerland is committed to implementing measures to reduce excess nitrogen. To meet these commitments, Switzerland regulates the nitrogen cycle under the provisions of relevant laws in environmental protection, water-course protection and agriculture.

Nitrogen compounds

Nitrogen compounds

Reactive nitrogen compounds produced as a result of human activity lead to a cascade of effects in ecosystems; for example, to eutrophication of water courses and to over-fertilization and acidification of soils, plus they threaten biodiversity and human health. The most important compounds are nitrogen oxides (NO_x), ammonia (NH_3), laughing gas (N_2O) and nitrate (NO_3^-), which, through a range of processes in the atmosphere, hydrosphere, pedosphere and through human activities, are constantly interchanging with one another.

Methodology

Methodology

The nitrogen-relevant processes in Switzerland are separated into four subsystems:

- agriculture and forestry (L),
- production/utilisation of goods (P),
- environment (U),
- waste management (A).

In addition, the special subsystem "abroad" is required so as to encompass imports and exports. The subsystems are broken down into "processes"; for example, livestock, transport, atmosphere, etc. Processes are both source and sink of the respective nitrogen flux in the system.

The methodology used for the current material flux analysis is based on the guidelines found in FOEN's "Material Flux Analysis Switzerland" from 1996.

For the quantification of nitrogen fluxes, mainly existing data were used, sourced primarily from (research) projects and publications from FOEN, ART, WSL, Eawag and FiBL.

The quality of the loading figures varies greatly. For certain fluxes the quantitative margin of error is known; for the majority of fluxes the margin of error is estimated.

Results for the year 2005

The greatest nitrogen loads are exchanged between the subsystems agriculture and forestry, environment, and abroad. The situation in the subsystem agriculture and forestry is particularly complex: there are not only countless flux pathways, but significant transformations take place between the nitrogen compounds.

Results for the year 2005

The largest and most important fluxes of ecologically relevant nitrogen compounds are:

> Feed crops from agricultural soils for livestock: 132 kt N (L8)
> Farm manure/excrement from livestock on agricultural soils: 86 kt N (L1)
> Outflow via rivers: 73 kt (U14)
> Carried abroad in the air: 56 kt N (U10)
> Mineral fertilizer (imported) on agricultural soils: 52 kt N (I4)
> Imported in the air from abroad: 44 kt N (I8)
> Waste water from waste-water treatment plants: 43 kt N (P8)
> Emissions from livestock into the atmosphere: 42 kt N (L4)
> Products/food from livestock: 35 kt N (L3)
> Leaching from agricultural soils: 34 kt N (L5)
> Feed imports for livestock: 32 kt N (I3)
> N_2 fixation by agricultural crops: 32 kt N (U1)
> Imported foodstuffs and other materials: 25 kt N (I2)

Trends in material fluxes 1994–2005

Trends in material fluxes 1994–2005

> *Decreasing material fluxes:* Thanks to successful measures in the areas of combustion and transport, NO_x- emissions in the atmosphere have decreased, with a corresponding decrease in deposition in soils. Further fluxes have also been reduced: these include farm manure application on agricultural soils, inland production of animal feed, use of mineral fertilizer, as well as NH_3- and N_2O emissions in the atmosphere. Additionally, N emissions from waste-water treatment plants are lower due to a targeted reduction programme. The nitrogen load in cross-border rivers also shows a declining trend.
> *Increasing material fluxes:* The import of animal feed has increased. Imports of primarily soya have risen. Possible reasons for this are the higher use of feed concentrates in livestock production and the ban on animal meal as feedstuff (due to BSE).
> *Fluxes with negligible change:* Products from livestock and crop production, exports from the foodstuff industry, as well as leaching and runoff from soils have all shown little change during the period 1994 to 2005.

Detailed information on the most important nitrogen fluxes between 1994 and 2005 are set out in the following table.

Fig. A > Total system Switzerland 2005; nitrogen fluxes between the subsystems

The largest nitrogen fluxes in the total system in 2005. The total system incorporates four subsystems, which each comprise a number of processes. The arrows indicate the sum of all the nitrogen fluxes flowing between the subsystems, in 1000 tonnes N per year (kt N/year) for the year 2005. Figures given in black are the total fluxes of nitrogen (mean values and margin of error), which include both ecologically relevant nitrogen compounds as well as atmospheric nitrogen, and in blue, atmospheric nitrogen fluxes only.

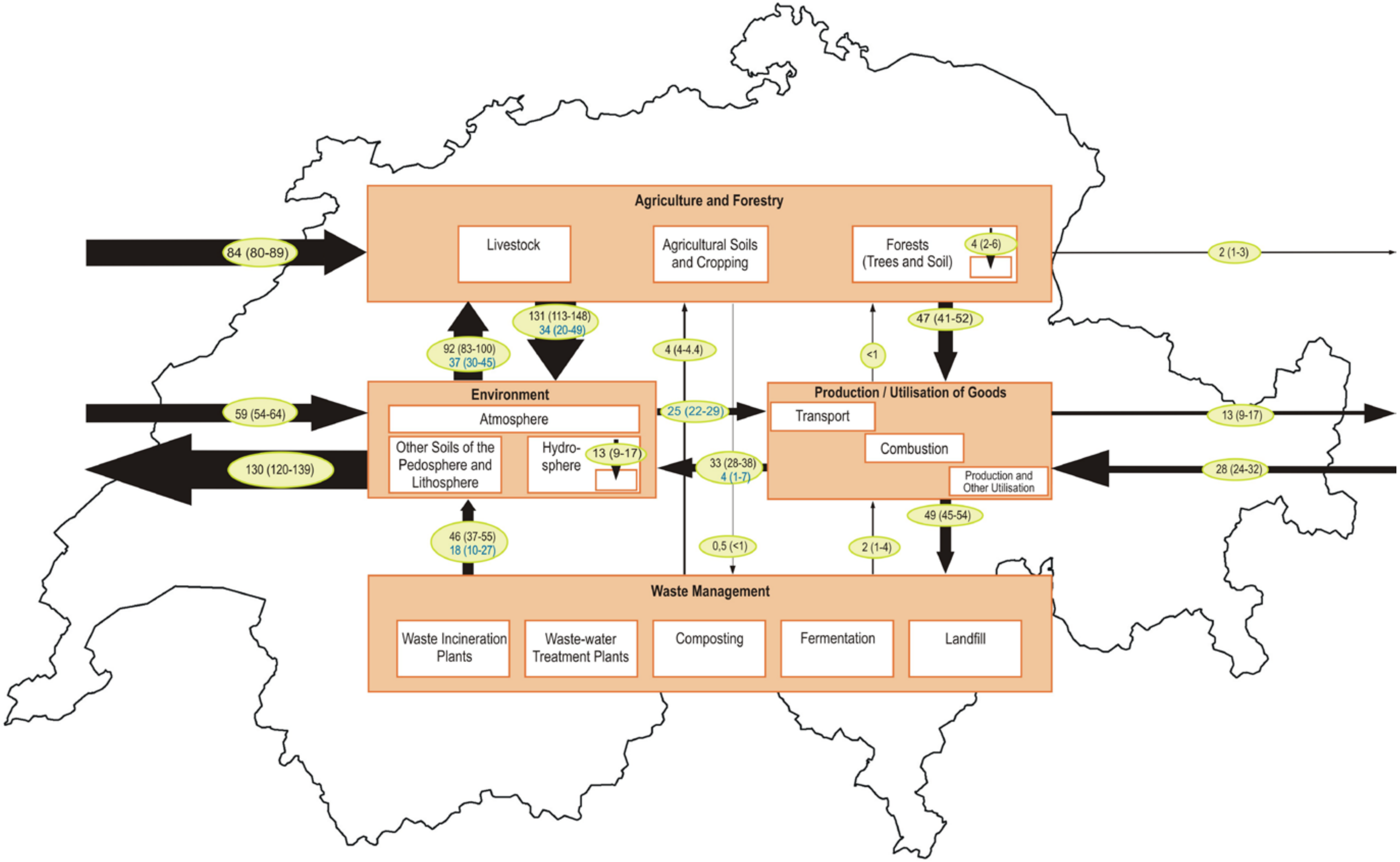
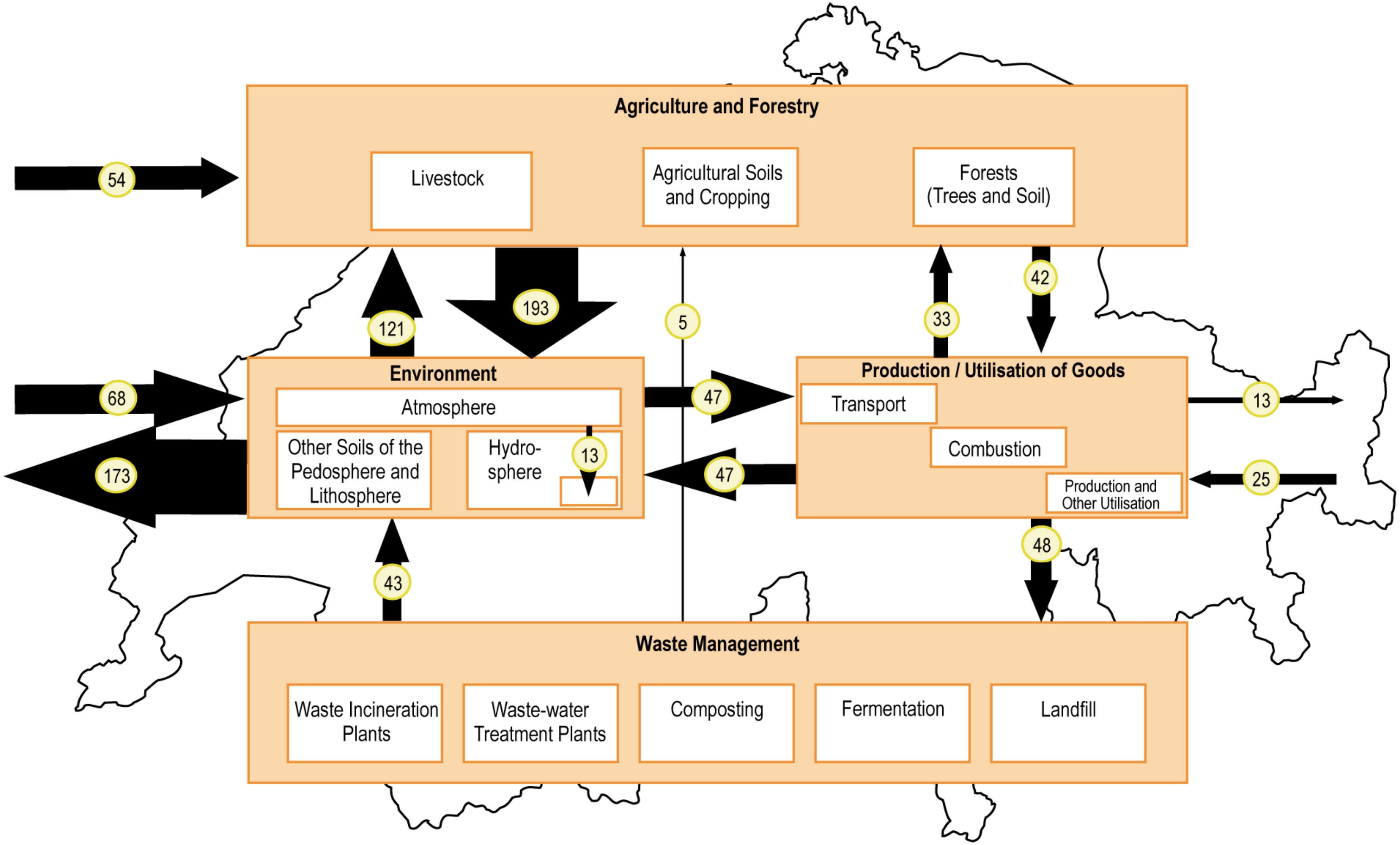


Fig. B > Total system Switzerland 1994; nitrogen fluxes between the subsystems

The largest nitrogen fluxes in the total system in 1994. The fluxes from 1994 have been transformed into the new system, whose subsystems are defined slightly differently than they were in the original (PG N-Haushalt CH 1996). The total system incorporates four subsystems, which each comprise a number of processes. The arrows indicate the sum of all the nitrogen fluxes flowing between the subsystems, in 1000 tonnes N per year (kt N/year) for the year 1994. Figures show the total fluxes of nitrogen (mean values), which include both ecologically relevant nitrogen compounds as well as atmospheric nitrogen.



PG N-Haushalt CH (1996), GSK 1993 (1990).
The export of 173 kt N from Environment includes 98 kt N outflow via rivers + 5 kt N outflow via groundwater + 70 kt N carried abroad in the air (exported).
The import of 25 kt N (rounded off) for Production/Utilisation of Goods includes 24 kt N in imported foodstuffs and other materials +0.5 kt N in wood imports.
The import of 68 kt N for Environment includes 47 kt N imported from abroad in the air +21 kt N inflow via rivers.
The flux of 193 kt N from Agriculture and Forestry into Environment includes 83 kt N from denitrification in agriculture (of this 8 kt N_2O-N) +51 kt N NH_3 gas +37 kt N NO_3 loss from agriculture + 12 kt N NO_3 loss from forests + 10 kt N denitrification from forests

Tab. A > Comparison of the largest nitrogen fluxes 1994/1990 vs. 2005

Comparison of the largest nitrogen fluxes from the material balance in Switzerland 1994/1990 (PG N-Haushalt CH 1996; GSK 1993) with current nitrogen fluxes for the year 2005 (present study). The designation of fluxes is from the present study (figures 2005). Comment on the designation of nitrogen fluxes from 1994 is given in cases where some room for interpretation exists. Fluxes with pure atmospheric nitrogen (N2) are given in blue.

	1994/1990 [kt N]	2005 [kt N]	Comments on data quality	Explanation of trends 1994 to 2005
Agriculture and Forestry				
L8: Feed crops from agricultural soils for livestock	180	132	1994 value, feed from agricultural soils for livestock, from GSK 1993. No further details available; e.g. not stated whether N_2 loads were considered. Value is likely to be too high.	
L1: Farm manure/excrement from livestock on agricultural soils	97	86	1994 value taken from Greenhouse Gas Inventory, FOEN 2009b. The value from GSK 1993 (Flux from farm manure from livestock on agricultural soils and crops) of 155 kt N seems to be too high; no further details available.	
L4: Emissions from livestock into the atmosphere L6 (r): Emissions from agricultural soils into the atmosphere Total L4 + L6 (r) L6 (nr): Emissions of N_2 from agricultural soils into atmosphere	 51 (NH_3 gas) 8 (N_2O emissions) 59 75	42 11 53 28	Denitrification of N_2 has high degree of uncertainty. Margin of error 1994: 50–100 kt N.	Decrease of total NH_3 emissions due to reduced animal numbers, reduced mineral fertilizer use, improved farm manure management and changes in animal husbandry. High degree of uncertainty for denitrification.
L3: Products/food from livestock L9: Products/food from cropping Total L3 + L9	 42 (Agricultural products)	35 10 45	1994 value from PG N-Haushalt CH 1996. Further 1994 value for comparison, from OSPAR: products/food from livestock: 28 kt N; products/food from cropping: 10 kt N.	Increase in animal products due to intensification of animal husbandry. Increase in productive livestock numbers since 2004 (see also Fig. 16).
L5: Leaching/runoff from agricultural soils into the hydrosphere	37	34	No current values are available. Value for 2005 is derived (see appendix, flux L5).	Decrease compared to 1994 expected (estimate).
L14: Leaching from forests into the hydrosphere	12	9	1994 value with high degree of uncertainty. Margin of error 1994: 8–16 kt N.	Leaching is dependent on forest area and deposition on forest soils. A small increase of forest area and a clear decrease in deposition have taken place. These explain the net decrease in leaching.
L15 (r): Denitrification from forests (without N_2) U11 (r): Denitrification from other soils (without N_2) Total L15 (r) + U11 (r) L15 (nr) Denitrification N_2 from forests	 ≤ 1 9 (Denitrification non-agricultural soils)	1.1 0.4 1.5 6	Denitrification of N_2 has high degree of uncertainty. Margin of error 1994: 6–12 kt N.	High degree of uncertainty; denitrification is difficult to determine. N_2 makes up the largest part of the flux.
U13 (r): Denitrification N_2O, NO_x from the hydrosphere U13 (nr): Denitrification N_2 from the hydrosphere Total U13 (r) + U13 (nr)	 13 (incl. N_2)	1 (without N_2) 11 (N_2) 12	High degree of uncertainty in estimating N_2. Margin of error 1994: 9–18 kt N (incl. N_2).	

	1994/1990 [kt N]	2005 [kt N]	Comments on data quality	Explanation of trends 1994 to 2005
Production/Utilisation of Goods				
P8: Waste water from waste-water treatment plants	Unknown – internal flux	43		
P2: Emissions of NO_x, NH_y from transport into the atmosphere P3: Emissions of NO_x, NH_y from combustion into the atmosphere Total P2 + P3	 47 (From combustion processes; of this 43 NO_x)	18 8 26	Based on new results (FOEN 2009a) the NO_x emissions for 1994 were overestimated at that time by about 5 kt N.	Decrease in emissions thanks to air pollution controls.
P10: Export from foodstuffs industry and other products	13	16	Estimates difficult as average N load of export products is uncertain. Margin of error 1994: 10–15 kt N	
Environment				
U14: Outflow via rivers	98	73	1994 value: loads measured at Swiss borders. Average for the period 1986–1995. Data NADUF, Eawag. 2005 value: mean value Rhine 1995–2007; extrapolated for whole Switzerland. Data NADUF, Eawag. Margin of error 1994: 90–110 kt N.	Decrease thanks to successful reduction measures in industry, transport and agriculture.
U16: Export via groundwater	5	< 1	1994 data with high degree of uncertainty.	The value from GSK 1993 (SRU 209) is deemed too high; few data sources are available.
U3: Deposition in forests U4: Deposition on agricultural soils U7: Deposition on other soils of the pedo- and lithosphere U9: Deposition in water courses Total U3 + U4 + U7 + U9 (total deposition)	32 32 13 3 80	27 27 11 3 69	Based on current knowledge of rates of deposition, the total deposition for 1994 has been separated into four zones – forests, agricultural soils, other soils and water – so as to create a basis for comparison to 2005.	Decrease in total deposition and deposition in each zone (except water). The value of 3 kt N for water courses appears constant due to rounding off.
U10: Carried abroad in the air (export)	70	56	Margin of error 1994: 55–85 kt N (of this 30–55 NO_x and 20–35 NH_y).	Decrease thanks to air pollution controls; primarily a reduction in NO_x.
U1: N_2 fixation by agricultural crops	45	32	Quality of 1994 data is poor. Margin of error 1994: 30–60 kt N. 1994 value from THG Agricultural Inventory and OSPAR: 37 kt N.	Decrease due to reduced share of legumes in cultivation. Estimation difficult.
U5: N_2 use in transport, combustion, processes	47 (Combustion processes)	25		Decrease thanks to measures in air pollution control.
U12: Leaching from other soils into the hydrosphere	6	11	Data for 1994 and 2005 are poor. Margin of error 1994: 2–10 kt N.	
U2: N_2 fixation in forests	12	5	Quality of 1994 data is poor. Margin of error 1994: 8–16 kt N.	Trend has not really occurred, but is a result of methodology. Likelihood of no real increase or decrease.

	1994/1990 [kt N]	2005 [kt N]	Comments on data quality	Explanation of trends 1994 to 2005
Waste Management				
A5: purified waste water from waste-water treatment plants into the hydrosphere	30	26		Decrease due to improved nitrogen elimination in waste-water treatment plants.
Abroad → Inland				
I4: Mineral fertilizer (import) in agricultural soils P1: Mineral fertilizer (domestic production) Total input mineral fertilizer A7: Biosolids for farm manure A9: Compost for agricultural soils Total recycling fertilizer Total mineral and recycling fertilizer	33 33 66 5 (Biosolids, compost) 71	52 << 0.5 52 1 3 4 56	Total mineral and recycling fertilizer for 1994 from THG Agricultural Inventory and OSPAR: 65 kt N.	Decreased use of mineral fertilizer. Decrease use of recycling fertilizer due to ban on biosolids for manure; transition provisions for selected areas ended on 30 September 2006.
I8: Imported via air from abroad	47	44	1994 figures from EMEP 1995. Margin of error 1994: 37–57 kt N (of this 27 NO_x and 20 NH_y).	
I2: Imported foodstuffs and other materials I5: Wood imports Total I2+I5	24 0.5 25	25 2 27		Increased use of wood.
I3: Imported feed for livestock	21	32	1994 value from OSPAR: 26 kt N.	Increased soya imports.
I1: Inflow via rivers	21	15	Value for 2005 estimated from 1994 data. Margin of error 1994: 15–25 kt N.	

Interpretation

Interpretation

The most important "driving" material fluxes are the input of nitrogen from animal feed and imported commercial fertilizer, which through combustion processes causes nitrogen-oxide emissions, as well as ammonia emissions from agriculture. Together with the way in which agricultural soils are prepared and planted, these are responsible for stimulating all other fluxes; that is, the "induced" material fluxes such as emissions from soils, leaching and runoff from soils into the hydrosphere, outflow abroad, and deposition from the atmosphere onto soils. It is in these induced material fluxes where we see the problems caused by high nitrogen loss: reduced soil fertility, loss of biodiversity, loss of water quality, "dead zones" in estuaries, adverse effects on human health, etc. To tackle these problems requires, firstly, a reduction in the driving material fluxes and, secondly, a closure of the cycle. This involves one of the greatest challenges in reducing nitrogen losses: partial strategies to avoid losses can lead to losses via another channel. An integral approach goes beyond just looking at nitrogen and encompasses, among other things, resources and implications for climate protection.

In agriculture, commercial fertilizer imports have in fact decreased; animal feed imports (mostly soya) have, however, increased.

Regarding the emission of air pollutants, oxidised compounds (NO_x) have clearly decreased thanks to various reduction measures in the areas of transport and combustion;

on the other hand, the reduced compounds (NH_y) that largely originate in agriculture have only slightly decreased. As a result, the decrease in the deposition of oxidised N compounds is greater than the decrease in reduced N compounds. The Swiss NO_2 emission limits continue to be regularly exceeded in town centres and along highways. The total N deposition exceeds the Critical Loads for nitrogen in many parts of Switzerland.

Nitrogen inputs from household and industrial waste water into the hydrosphere have decreased, despite rising populations. This is thanks to an investment programme aimed at improved elimination levels in waste-water treatment plants. Diffuse inputs into the hydrosphere also show a declining trend. However, the international goal to halve the nitrogen inputs into the Rhine River and the North Sea during the period 1985 to 2001 clearly failed, which is also an issue for the other member states.

The flow of goods such as foodstuffs, fuel products, wood, etc. has changed little in terms of both imports and exports. Noteworthy for these fluxes is the demise of domestically produced mineral fertilizer and the overall reduction in the use of mineral fertilizer. At the same time, feed imports – a driving flux – have risen strongly (see above).

While bringing the material flux analysis up to date, gaps in the data and significant degrees of uncertainty in the nitrogen fluxes were identified. The quantification of these would be very demanding. This is particularly relevant for the induced fluxes. For the driving fluxes the data situation is better.

The trend in recent years shows that nitrogenous air pollutants from transport, industry and households have been effectively reduced; however, the same degree of success has not been achieved in mitigating the nitrogen problem in agriculture. Whereas transport and industry were previously the greatest nitrogen emitters, today it is agriculture. In the coming years the situation in this sector also needs to be improved.

In future the use of bioenergy (e.g. agrofuels) will intensify. The goal of current activities in this area is to develop systems that are highly efficient and economically optimal. The effects on the nitrogen cycle will initially be barely considered. The effects, however, could be relevant, because ammonia accumulates as a result of the production of methane gas from organic substances, alongside non-reactive atmospheric nitrogen and other by-products.