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Considerations for a reference indicator of Nitrogen and Phosphorus emissions from agricultural sources in the Danube Basin

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, June 17th, 2009

Affidavit

I, **EMMA ROCKE**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Considerations for a reference indicator of Nitrogen and Phosphorus emissions from agricultural sources in the Danube Basin", 105 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 17.06.2009

Signature

ABSTRACT:

The current water quality status of the coastal Black Sea area is considered satisfactory, however there is a concern that this situation may reverse with the agricultural development of CEE countries. Point source emissions are relatively easily identified and dealt with, however diffuse sources especially from agriculture constitute over half of the remaining nutrient loads. The development of an indicator to be used as a benchmark of national nutrient management in respect to the environmental protection of the Danube River Basin would help with the fair application of mitigation measures for diffuse nutrient sources. This study developed a material flow analysis of nitrogen and phosphorus through agricultural activities for Germany, Hungary and Romania as examples. Nutrient balances were calculated for agriculture as a whole. The MONERIS model was used to estimate N & P loads to the Danube Corridor and into the Black Sea. The results of these analyses were then applied to various potential indicators. When the nutrient balances of agriculture as a whole was analysed, it emerged that Germany's larger production of meat and animal products which includes a large amount of milk led to more nutrient losses to surface waters compared to Hungary and Romania. Upon closer inspection, the more mineral fertilizers and feedstuffs that were imported, the more nutrient losses to surface waters accrued. A 'nutrient surplus' was identified and defined as the excess nutrients resulting from all inputs into agriculture minus agricultural products produced. Efficient nutrient management through the application of a 'ceiling' quantity of imported nutrients for feeding livestock so that the least amount of nutrients are lost to surface waters is therefore a possibility. This would curtail losses from developed countries such as Germany whilst allowing new member states such as Romania to develop and grow.

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1. INTRODUCTION:

Motivation – (overview paragraph)

The lack of nutrient management in the Danube Basin has been a continuous concern since the early 1960's and particularly during the 1980's. The culprits of an excess discharge of phosphorus and nitrogen include agricultural runoff, municipal (including detergents as a source) and industrial waste. This has resulted in chronic algal blooms in the Danube delta and the western coast of the Black Sea, permanent hypoxic situations, which have killed many fish, ultimately impacting the drinking water supply, fishing and tourism sectors in the countries immediately surrounding the western coastal Black sea area. Due to economic breakdown, the present state of the North Western Black Sea is considered satisfactory, however it is assumed that this is the case due to recent economic recession in the former communist countries lying in the Danube Basin. The present challenge is therefore to prevent future pollution and eutrophication of the Black Sea whilst allowing for economic growth in the middle and lower regions of the Danube Basin.

Danube Basin & Black Sea

The Danube basin watershed covers 817 000 km^2 and 19 countries including EU-Member states, accession and non-accession states (see map in annex). It is the main tributary to the Black Sea, which has a surface area of 451 000km^2, and an average depth of 1240m. The Black Sea connects to the oceans via the Bosphorus Channel. The Danube River Basin is the 2nd largest river basin in the world and containing 19 states, the most international. A population of over 81 million people over this area represents a critical management situation, given the development potential of many post communist states in the Danube River Basin (ICPDR, 2004).

Before the economic breakdown of the post communist countries, agricultural production was strong in the Danube Basin, the result being massive algal blooms in the Danube Delta and western coastal Black Sea. This threw the whole ecosystem out of balance. As this algae consumes all available bottom oxygen when it decomposes after death, fish and wildlife populations were in danger as was the quality of drinking water in many EEC countries in the Danube River Corridor.

Regulation and International Law

In response to this phenomenon and the economic, political and ecological complexities of the different countries involved it was obvious that a universal framework or mechanism was necessary to manage the basin in the future. So, following the eutrophication problems of the 1980's, 'integrated river basin management', or IRBM became the predominant mechanism to deal with these issues and their impacts.

A number of institutional agreements led to the present IRBM practices. In 1985, the Danube countries at the time agreed on the 'Bucharest Declaration on water management of the Danube River' to coordinate water management activities. Unfortunately due to the unstable political situation in this region at this time the implementation of this was affected. This was however shortly followed by two mechanisms that did come into force. The Environmental Programme for the Danube River Basin (EPDRB), a cooperative regional agreement came into effect in September 1991 and focussed on setting up a coordination plan to address immediate needs and establish a game plan for long-term action. These plans included the development of a course of action for environmental management, diagnostic missions to identify key pollution sources, and the assessment of aquatic environmental quality in each region. The second mechanism, the "Convention on Cooperation for the Protection and Sustainable Use of the Danube River" is the legal instrument for cooperation and transboundary water management in the Danube River Basin. Its purpose is to ensure that the surface and ground waters of the Danube River Basin are managed sustainably and fairly. The eleven Riparian states that signed the Convention at the time, which has since grown to 14 states have promised to take "all appropriate legal, administrative, and technical measures to at least maintain and where possible improve the current water quality and environmental conditions of the Danube River and of the waters in it's catchment area, and to prevent and reduce as far as possible adverse impacts and changes occurring or likely to be caused."[1] The works of the International Commission for the Protection of the Danube River (ICPDR) is based on this last convention.

The ICPDR and others have worked on many projects to facilitate the signatories of these conventions comply and negotiate specific mechanisms more easily.

DANUBS study

One such project is the DANUBS, or Nutrient Management in the Danube Basin and its impact on the Black Sea (2005). Nutrient management is such a complex practice given the size of the Danube catchment, and nutrient balances were not well understood. Certain management tools and models were missing on order to properly coordinate and agree on a common management method. In particular the emission estimations, especially those from diffuse sources did not match up to the loads into the river system. This was due to the fact that the mechanism of nutrient retention in groundwater and river systems was poorly understood and therefore the monitoring already in place did not measure total transported loads, but rather only critical concentrations in the river. Work had to be done to develop effective tools that support the planning needed for better nutrient and water quality management on a catchment scale, which is where the DANUBS project came in.

The objectives of this project were fourfold. Firstly, attention needed to be paid to the improvement of the knowledge on the source, pathways, stocks, losses, and sinks of nutrients in a large river catchment. Secondly, the knowledge on the effects of nitrogen, phosphorus and silica on the downstream ecosystems needed to improve. Thirdly, nutrient management tools in the Danube Basin needed developing and finally, the development of future scenarios on which to base nutrient management prognoses were to be envisioned.

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[1] ICPDR website: www.icpdr.org accessed May 18th, 2009

The approach taken to address these objectives included a variety of research elements. One, most importantly sought to improve the understanding of the nutrient driven processes in the Danube catchment and the portion of the Western Black Sea influenced by the Danube River. This was accomplished via literature data reviews accompanied and verified by fieldwork. The research focussed on nutrient balances with a particular focus on diffuse sources and transport, retention and losses of nutrients and Silica in groundwater, surface water and finally along the Danube River. Focus was also paid to the functioning of the Black Sea ecosystem and how the Danube River nutrient discharges was affecting it.

Mathematical models were applied and improved in order to quantitatively assess the travel routes of nutrients from their sources to the Danube River and eventually into the Black Sea. Such models included the MONERIS emission model, the Danube Water Quality model, the Danube Delta model and the Black Sea Model.

Lastly a formulation of strategic planning on a catchment scale was attempted. Considerations were made for the conception of comparable, periodic, Basin wide nutrient balances. Finally different solutions for future nutrient management strategies were formulated and evaluated given the results of the previous project goals/objectives (DANUBS, 2005).

DANUBS results:

After this four year long study, the results coming from the source and calculated load of diffuse sources of nitrogen and phosphorus in the River Basin will be focussed on. The MONERIS model (Behrendt H., 2008) (will be described in the methodology chapter) was used to estimate nutrient emissions from 1998 to 2000 for 388 sub-catchments in thirteen countries (see below). This model was then applied to illustrate the development of nutrient loads in the Danube over time, in order to express the relation between intensities of human drivers and the consequential reaction of the River Basin in the past.

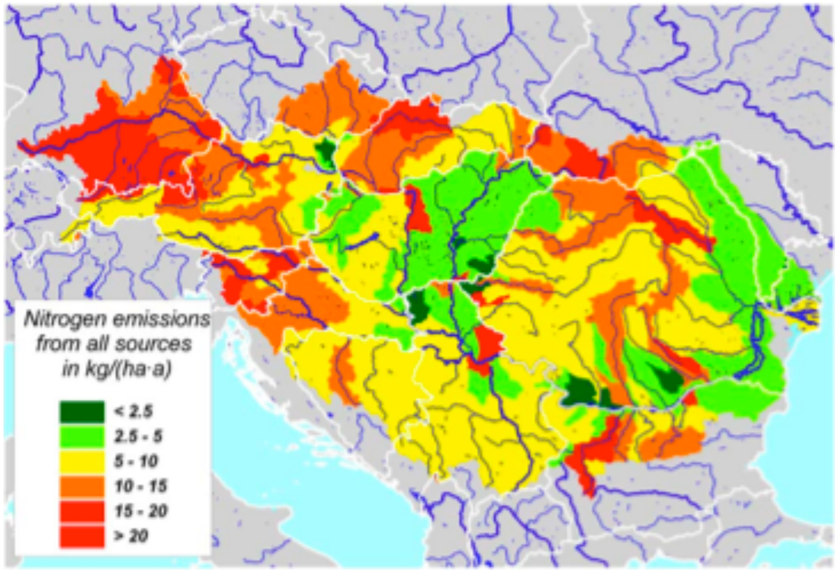


Figure 1 **Nutrient emissions from all sources (surface runoff, erosion, groundwater, tile drainage, atmospheric deposition, point discharges and urban areas) within the subcatchments of the Danube in the time period 1998-2000. (DANUBS, 2005)**

For the study period 1998-2000, 756 kt/year of nitrogen and 68 kt/year of phosphorus were emitted by all pathways. 77% of nitrogen emissions and 53% of Phosphorus emissions were emitted from diffuse sources. The dominant pathway for nitrogen was Groundwater at 43% and for phosphorus the most emissions came from point source discharges at 47%. When comparing naturally caused emissions to human induced ones, the human impact was 12 times higher for nitrogen and 10 times higher for that of phosphorus. 32% and 46% of total phosphorus and nitrogen emissions respectively were due to agricultural activities (Figure 2).

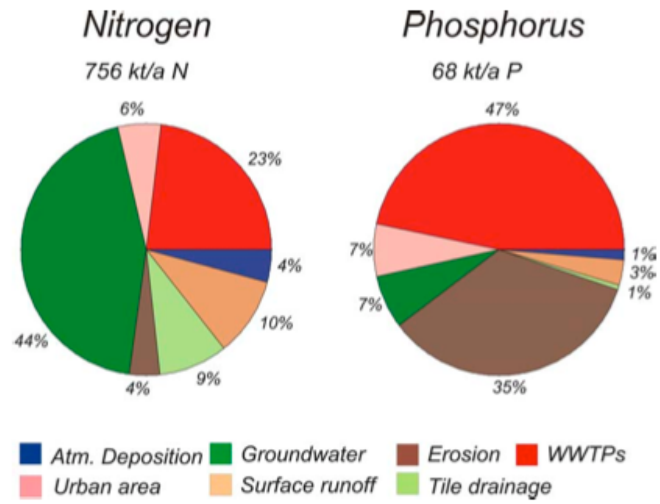


Figure 2: **Nutrient emissions from different diffuse pathways and point sources for the total Danube from 1998-2000. (DANUBS, 2005)**

Looking at these results on a regional basis, these emissions obviously vary considerably depending on the intensities of a countries land use as well as it's differing hydrological and hydro geological conditions. Figures 3 and 4 illustrate the country-by-country split in human and natural phosphorus and nitrogen emissions. Nitrogen emissions are shown as being predominantly emitted through agricultural pathways for all countries except for Hungary, Serbia, Montenegro, Bosnia and Herzegovina.

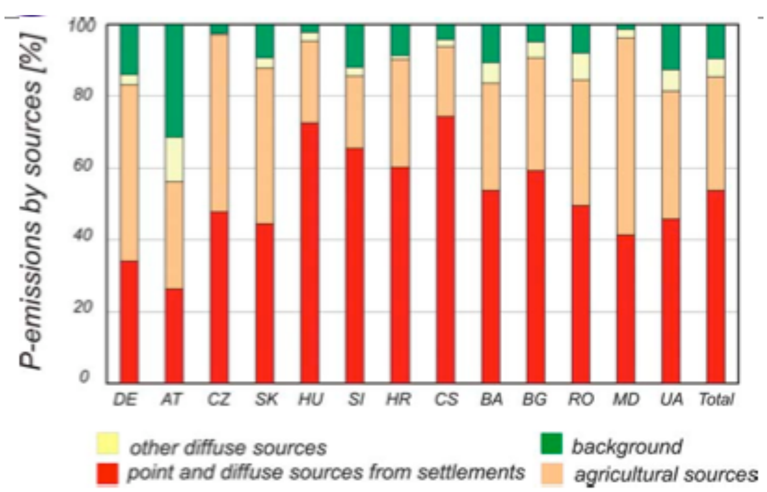


Figure 3: **Phosphorus from human sources and natural background sources into the Danube area of the different countries from 1998-2000. (DANUBS, 2005)**

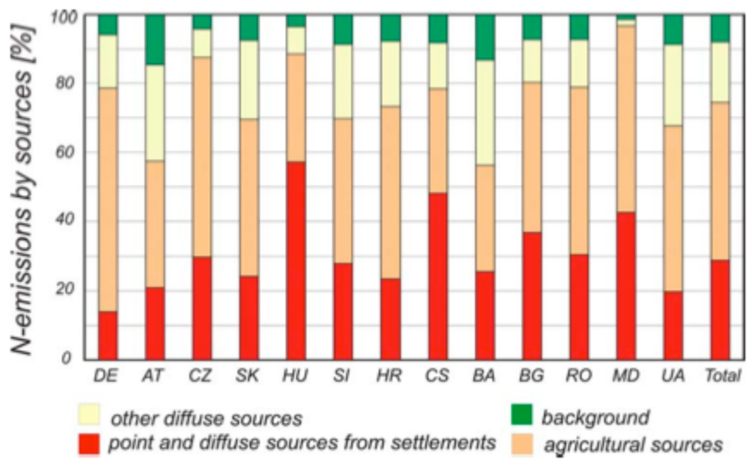


Figure 4: **Nitrogen from human sources and natural background sources into the Danube area of the different countries from 1998-2000. (DANUBS, 2005)**

Over time, nitrogen emissions have doubled from 1950 to 1980's, and then fell in the 1990's due to economic breakdown and reduction of land use intensities. It is important to understand that the emissions from diffuse nitrogen sources lag in time due to their residence time in the groundwater and the different retention rates in the various unsaturated zones. It takes several years up to several decades for the nutrients to percolate their way through the ground water to the surface water. The diffuse emissions of phosphorus are much lower and less known over time, but are estimated to be about 10% above the level of the 1950's (DANUBS, 2005) (Figure 5).

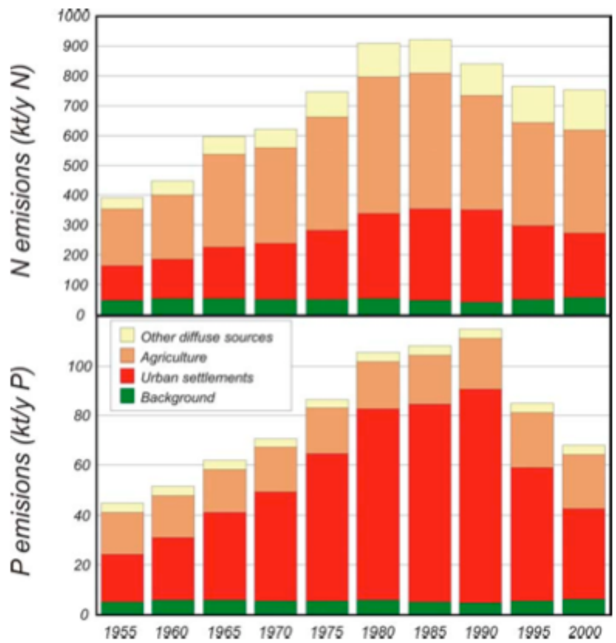


Figure 5: **Changes of nitrogen and phosphorus emissions into the river system of the Danube from 1955 to 2000. (DANUBS, 2005)**

To conclude the results of the DANUBS study, upon which this thesis will build, it is clear through the project results that agriculture plays an enormous role in diffuse Nitrogen emissions into the Danube River and into the Black sea. Recommendations made by the DANUBS study included policy measures focussing on long-term control of all anthropogenic point and diffuse sources of nutrients through the application of a precautionary principle. Specifically, integrated production and the optimisation of area specific production was suggested for economical and ecological sustainability.

Definition of Research Problem

As has been described above through the DANUBS study, over the last 50 years, the water quality and biodiversity of the Danube River Basin has steadily deteriorated with the increasing nutrient emissions. This state has improved since the early 1990's. Almost 80% of the Danube's wetlands have disappeared over this period, and nutrient loads have increased 10-12 fold from the 1960's to the early 1990's, which has since decreased due to the economic breakdown of post communist countries. The resulting eutrophication of the Danube delta and Coastal Black Sea area in the 1980's affected critical habitats of Danube fauna and flora species as well as drinking water quality in areas immediately surrounding the coastal Black Sea area.

In order to avoid these conditions and worse in the future, a reduction in nutrient loads is necessary. With such a huge River Basin area and varied geography, culture and politics this is not nearly as easy as it sounds. The DANUBS study was a good starting point, as it documented the past and present behaviour of the Danube River Basin and it's inhabitants. In particular, the behaviour of 'hidden flows' such as percolation, runoff and erosion were further understood with the help of models such as MONERIS. It also created future scenarios attempting to predict what would lie in store for the Black Sea given certain future behaviour. The study estimated that for a healthy river Basin, 1960's levels of nutrient loads could be considered 'tolerable'. It has been estimated that this 'tolerable' level of nutrient loads would reduce the amount of phytoplankton biomass production to an acceptable level, which was pinpointed as the determining factor for a healthy River Basin and Black Sea.

Identifying the biological culprits of the eutrophication problem in the Danube River basin is an important starting point for future mitigation of this problem. The next step however is to translate these recommendations and results into a policy that is understandable, fair and agreeable to all countries involved. This is where a close analysis of these scientific results is necessary, combining them with political and economic structures that make sense to all parties. This thesis will address the issue of non point pollution from agriculture that, if broken down in more detail, can help identify an indicator that can help all parties move forward with a fair and effective end policy. First of all though, an overview of the complexities of international river basin management from an economic and legal point of view will be established.

EU Water Framework Directive

The EU Water Framework Directive sets the groundwork towards eventually achieving good ecological status in the Danube River Basin and the Black Sea. The goal of the directive states that all European water bodies should meet ‘Good status or good ecological potential” by 2015. As stated in Article 3 par. 5, “Where a River Basin extends beyond the territory of the Community, the member state or member States concerned shall endeavour to establish appropriate coordination with the relevant non-member states, with the aim of achieving the objectives of this Directive throughout the River Basin district”[2]. The principal difficulty in transboundary river basin management such as that of the Danube is that it can only be achieved if neighbour countries with different cultures, different politics and different levels of economic development can effectively cooperate.

The International Commission for the Protection of the Danube River or ICPDR has taken the first step towards overcoming this challenge. In line with article 13 of the WFD (par 2: “…Member state shall ensure coordination with the aim of producing a single international river basin Management Plan”, this step has taken the form of a River Basin Management plan to be put together by 2009. This will entail national and basin-wide measures as well as setting a structure for more detailed plans at the national level. Many different actions have been initiated which will help contribute to and draft this final plan. The DANUBS was one such project, as was Joint Danube Surveys aimed at collecting detailed data in the whole of the Danube River Basin. Finally, an intercalibration exercise was based on this data in order to harmonize national assessment methods of each Danube River Basin country. Based on all of these actions, all data will be collected from which measures will formulated that will further reduce river basin pollution in the DRC and Black Sea.

These measures are all heading in the right direction as far as alleviating nutrient loads in the Danube River however past research has outlined the gaps in knowledge as far as the dynamics of large-scale pollution is concerned. In order to negotiate a fair way of alleviating water pollution, it is of the utmost importance that it is well understood.

[2] DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy.

Many studies have focussed on small scale pollution however not many of the large scale studies have taken into account the heterogeneity of aquifers and the physical links between the original source of pollutants and their downstream effects. Policy makers need to see a cost associated with a particular control method however before a cost benefit analysis can even be attempted properly and accurately, more needs to be known about a) the size of loads, b) the relationship between loads and environmental damage and c) the relationship between human activities within the drainage basin and the nutrient loads to coastal waters (Elofsson et al, 2003).

There have been various studies done focussing on cost effective reduction of non point nutrient emissions however in every case the uncertainties render each one a risky choice for a potential politician or policy maker. These models will be discussed in more detail in the discussion of this thesis, but to complete the picture of the research problem a few examples are as follows. Katarina Elofsson calculated the cost effective solutions to nutrient load reductions in the Baltic Sea using a chance-constrained model. She concluded that reducing emissions by 50% under stochastically behaving loads could increase costs by up to 80%. Similarly, Ing-Marie Gren (2000) and Henk Folmer (2000) also considered stochastic pollution and concluded that the higher risk aversion, the less abatement and the smaller the net benefits of abatement. Tomasz Zylicz reviewed the potential effectiveness of marketable permits (UNEP, 2005) and taxes (Wade, 2009) to allocate abatement effort. Permits were found to reach targets cost effectively in theory assuming an accurate and universal monitoring system is in place, however taxes were found to occasionally miss the environmental target. One obvious solution to this problem of stochasticity is to monitor non-point source pollution, however Erik Romstad, in his paper “Team approaches in reducing nonpoint source pollution” (Romstad, 2003) found it technically difficult and costly to monitor nonpoint source pollution. In order to work around this problem, he suggests focussing on readily observable factors and applies economic instruments to these such as taxes or tradable permits as mentioned earlier.

The common thread linking all these dilemmas together is the unpredictability of nonpoint source pollution, a huge percentage of which stems from agricultural activities. If this variable could be understood in more detail through appropriate development, combined with proper scenario formulations, the uncertainties associated with the described economic mitigation measures would be considerably reduced thereby resulting in a more usable cost benefit scenario.

Outline of the main research question

Given the problems described in the previous section, if a common agricultural indicator could be formulated, combined with public participation processes, the formulation of a fair consideration for nutrient distribution along the Danube River Basin could be attained.

The main question posed for which an answer will be attempted in this thesis is: does there exist a common flow of nutrients from agricultural activities amongst all Danube River countries that could be applied as an indicator upon which future policy actions could be based upon? Put more simply, what is the amount of nutrients a country may release to the Danube? The variable populations, surface areas, intensity of agricultural production and not least of all economic states of the countries lying in the Danube Basin are all factors that must be considered when fairly evaluating such an indicator or indicators.

Hypothesis

In keeping with the previous studies, which have measured the sources and pathways of Nitrogen and Phosphorus into the Danube River, it is already known with much certainty that base flow will predominate the flow of diffuse nitrogen whereas erosion will predominate diffuse phosphorus flows (Brunner et al, 1997).

More specifically, literature and past studies demonstrate that the inputs of nitrogen and phosphorus fertilizers to agricultural soils in the form of mineral fertilizers and manure have been found to exceed outputs by agricultural products. Not only mineral fertilisers are to blame but also animal stocking densities, which are calculated to be directly related to nutrient flows to aquatic ecosystems. In both these cases the manure application or production exceeds the amount actually needed for the crops themselves. Additionally nitrogen volatizing to the air is partly deposited in remote areas, which are not under agricultural production, and leads to an excess of nitrogen in this areas. The excess nitrogen percolates to downstream ecosystems, eventually leading to problems in the aquatic ecosystems. In the case of phosphorus, the excess fertilizer and manure production on agricultural areas also creates phosphorus surplus a lot of which is stored in the soil, and some of which will erode and runoff into aquatic ecosystems (Carpenter et al, 1998).

The situation, which will be further discussed by this thesis, is the difference in N/P ratios within the EU15 countries versus that of central- and eastern European (CEE) countries, including those that are newly joined into the European Union (NEU12). Nutrient balances up until the present have calculated strong positive NP balance within the EU15 but negative, and declining NP balances in CEE and NEU12 countries (Csathó & Radimszky, 2009). Based on this background, the results of this thesis are expected to demonstrate results similar to these.

Aims and structure of thesis

Many studies have been put forward focussing on the issue of surplus applications of nitrogen and phosphorus, NP balances and the effects of these on the ecological status of the Danube River Basin. The aims of this thesis will be to calculate in detail the flows of nitrogen and phosphorus into the Danube via agricultural activities. A flow or flows will then be extracted and analysed with the aim of suggesting it as an indicator. The results section and final aim will be to discuss the applicability of certain indicators as a benchmark for national nutrient management. These indicators will be set in relation to critical loads from nutrient emissions above which deterioration of a good ecological status due to eutrophication of the North Western Black sea coastal area has to be suspected.

The structure of this thesis will start with a brief background from OECD Country studies, which will be summarized in a background section to illustrate the ecological, political and social states of the three countries chosen. This will be followed by the methodology of how exactly the material flow analysis was attempted and calculated, using the MONERIS model, OECD method and Material flow analysis combined. Finally the results of the calculations will be presented and discussed in detail.

BACKGROUND: Countries

Hungary

Agriculture in Hungary plays an important role in the economy. This sector has experienced a considerable decline over the past years since 1990. A 14% decline in yearly GDP in 1989 to around 3% in 2004 has resulted in a 14% reduction in the volume of agricultural production. Since these production numbers, cereal crops have increased slightly however livestock has decreased, predominantly in milk production.

Reasons behind such a decrease in production involved the transition from a centrally planned to a market economy. This has shifted farm ownership patterns, productivity and competitiveness and has resulted in an initial drop in agricultural production, investment and a rise in debt levels. Private family farms benefitted with a 15% rise in land area in the early 90's to over a 50% rise in land area by 2003-2004. As these smaller farms tended to be less productive, farm inputs such as fertilisers, pesticides, energy and water also decreased accordingly. Hungary was also unable to invest in measures such as manure storage facilities and erosion mitigation.

Farming in Hungary has been supported under the Common Agricultural Policy over the years, however this financial support has fluctuated and was reduced from 45% of farm receipts in the 80's to 12% of farm receipts in 1995-1997. This has risen to 28% of farm receipts by 2003 in a form of support that encouraged production. By 2005-2006, total annual budgetary support to Hungarian agriculture amounted to HUF 175 billion (EUR 660 million/65 EUR per ca), 10% of which contributed to agri-environmental measures.

How has environmental policy progressed over the years? Many obstacles have been created as a result of the centrally planned economy. In the first years of transition environmental policy was not a priority and due to the decrease in agricultural production these pressures decreased anyway. Accession to the EU however has required Hungary to develop policy responses to environmental pressures. Since the early to mid 1990's limits have been put on toxic elements in fertilizers, a 50% reduction in tax is administered to those farmers who adopt environmentally friendly practices (suspended in 1994), and soil conservation under the land act of 1994 has included per hectare payments to limit soil erosion. Pre accession funds are being used to administer these new policies, which are being phased in up to 2013, when CAP support reaches 100% of the EU15 level. To comply with the Nitrates Directive the 2002 Nitrate Action Programme has established Nitrate Vulnerable zones to regulate fertilizer and manure application and storage practices.

As far as agricultural performance is concerned, before transition to a market economy the main problem was excessive nutrient application, which led to significant water and air pollution. Since the 1990's however lack of nutrients and soil degradation has taken over as the predominant problem. Due to the reduction in farming intensity and land fragmentation, soil erosion persists as the key environmental problem in Hungary. Nearly 40% of farmland is affected by water erosion and has been compounded by the fact that less than 1% of arable land has been affected by soil conservation practices due to lack of funding.

According to the OECD, as far as water pollution is concerned, the low levels of nitrogen surpluses from agriculture have resulted in a low water pollution risk in during the 1990's. A recent increase in these surpluses since then however has increased environmental pressure in some areas. Within the Nitrate Vulnerable zones, which covers about 45% of land as of 2000-2002, 9% of groundwater monitoring points exceeded the EU nitrate drinking water standards. Similarly, 10% of surface water monitoring across the country exceeded the EU nitrate water standards. These problems are linked to a lack of financial capital to invest in environmental protection practices and inadequate knowledge of nutrient management practices.

In conclusion for Hungary, the overall environmental pressure has decreased since the 1990's, however there still exists a concern over water pollution in some areas. EU policies have been strengthened since accession however soil erosion continues to be a worry for this region. It has been suggested that an improved data collection could help this issue, which is being funded by PHARE (The Programme of Community aid to the countries of Central and Eastern Europe). Effective policy progress is essential as an expansion in agricultural production is projected for Hungary up to 2015 including further agricultural intensification in cereals, which take up a huge percentage of Hungary's land area, which will no doubt increase pressures on the Danube watershed in this area.

Germany

Germany's agricultural sector currently contributes to about 1.1% of GDP and 2.3% to employment. Over the period since the 1990s, livestock intensity has decreased by 6% however crop output has increased by 13%. As far as nutrients are concerned, inputs of inorganic nitrogen fertilizers have decreased by 6%, and phosphate fertilizers by 49%. A key environmental concern in Germany includes water pollution, especially in areas with intensive livestock production.

The CAP Framework mainly supports agriculture in Germany, contributing to 34% of farm receipts. The entirety of the agriculture budget stands at EUR 8 Billion per annum, a quarter of which is applied to less favoured areas and environmental measures. In contrast to Hungary, this worry does not stem from soil erosion problems. Nutrient surpluses however since the 1990's have been recorded as some of the highest in the EU15. Despite the closure of many livestock operations and greater efficiency of inorganic fertilizer use, (ie: crop production is up by 13% compared to 1990 and nitrogen fertilizer is down by 6%, phosphorus by 49%) which has helped lower these surpluses, N surpluses per Hectare are still considerably above OECD and EU15 averages. This result stems primarily from concentrated livestock areas.

To conclude for Germany, the new provisions under Agenda 2000 of the 2003 CAP reforms are expected to help curtail environmental impacts due to agriculture in the future. These provisions have helped encourage more sustainable farming practices, which are applied to approximately 30% of total agricultural area in Germany. Reduced land use intensity is encouraged in farms not undertaking these practices. Despite this progression however, the practice of agri-environmental programmes are still lowest in regions of high intensity farming. Future policies need to take this evidence into account.

Romania

As Romania is not an OECD country, no specific background from the OECD is presented, and so sources from ICPDR will be used instead[3]. The agricultural sector represents 8.1% of Romania's GDP and contributes to 29.7% of the labour force. It represents the largest land area of any one country situated in the Danube River Basin.

[3] http://www.icpdr.org/icpdr-pages/romania.htm ; accessed May 29th, 2009

As far as agricultural activities are concerned, livestock density varies between 0.16 and 0.65 animal units/ha, which is a little lower than the Danube average. As far as point sources are concerned, only 4.1% of rural and 47% of the urban population is connected to waste water treatment plants. For diffuse sources of pollution, a bit more comes from sewage compared to Germany or Hungary but as this study will only concentrate on diffuse sources from agriculture, this won't be discussed any further in this study. For agricultural diffuse sources however, the majority of emissions come from agricultural fertilizers with 0.39 – 8.7 kg P/ha and 6.91-23.6 kg N/ha (ICPDR, 2006). These values fit well within the range of values calculated for this study.

Politically, Romania is one of the newer member states to the EU. It is currently recovering from the post communist economic breakdown and expects to develop further, especially in the agricultural sector. This fact should be taken into account when considering potential nutrient driving indicators and accompanying mitigation measures.

Table 1: **List of areas, populations, densities and consumption trends for all three countries.**

	Germany	DRB portion of Germany	Hungary	Romania
Total Area (1000 Ha)	35709	5618	9303	23839
Agricultural area (1000 Ha)	17019	3230	5860	14857
Total population (1000's)	82506	9400	10160	21977
Population density (ca/ha)	2.3	1.7	1.1	0.9
Ca per Agricultural area (Ha)	4.8	3.0	1.7	1.5
Livestock density (AU/agr. ha)[4]	1.07	-	0.58	0.47
GDP/ca (USD)	34000	-	19400	10700

[4] http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database ; accessed June 10th, 2009

METHODOLOGY

General approach

The basis of this thesis lies in the material flow analysis of nitrogen and phosphorus stemming from agricultural production, including all processes that carry these same nutrients to water bodies of the Danube Basin and into the Black Sea. The results of this analysis included a special 'farm gate balance' of the agricultural process, which will be further explained at the appropriate section of this chapter. Finally a complete country nutrient balance was formulated which gave an overview of the final results as a whole. Again, these calculations will be further explained at the appropriate time.

This chapter will explain the material flow analysis applied for this study, which includes all agricultural nitrogen and phosphorus emissions via into the soil, water and air. This will be followed by the approach used to analyze the results and finally defend one particular indicator. As these losses have the potential to contribute to further pollution from a surplus balance of nutrients, the nitrogen balance could form the basis for indicators and models illustrating potential pollution risk in the Danube River Basin.

Choice of countries

Given the time constraints associated with this thesis, a material flow analysis of all the Danube countries was unrealistic. A more realistic number of three countries were therefore decided upon – considering the characteristic political, economical and social situations that vary to such an extent in the Danube Basin. It was therefore concluded that Germany, Hungary and Romania would be further analysed for the consideration of an indicator. As was discussed in the background, each of these countries can be considered as a representative of (1) Western Europe, (2) EEC (Eastern European country) and (3) NEU12 (countries newly accessed to the European Union). Germany was decided upon instead of Austria due to the past evidence of more pollution problems regarding surplus nutrient application to its soils (OECD, 2008).

Material Flow Analysis – procedure taken

System definitions

Every material flow analysis must start with the definition of its system boundaries, both in space and in time. As the scope of this project covers the development of an indicator that can be applied universally for future policy measures the choice here was an obvious one. For a space boundary, the politically defined region of Romania and Hungary, which lies within the Danube River Basin area, was chosen. This also made the calculations easier as data tends to be more easily accessible on a country by country basis. Germany had to be calculated differently as not all of its land area lies in the Danube basin. So the politically defined regions of Baden Württemberg and Bayern, which lie within the Danube River Basin, were chosen. In the EUROSTAT database the values for livestock and crops were available on a regional basis, the rest was approximated from Germany values as a whole. These calculations will be explained in detail later on.

For a temporal boundary the time period spanning 2000 to 2005 was chosen. It was assumed that this would be a long enough time period to avoid any short-term anomalies and nonlinear flows, whilst being recent enough to realistically illustrate present trends. Too recent data would most likely have caused data availability problems.

Data sources

The data used for this study came from three sources. FAOSTAT[5] from the food and agriculture organization of the United Nations was used for the most part. When

[5] http://faostat.fao.org/default.aspx: accessed on May 7th, 2009

particular data could not be found within this database, the EUROSTAT[6] database was used instead, as it tended to contain agricultural data for Europe in much more detail. This was helpful in cases such as Germany. Finally, all the MONERIS values originated from the Pressures and Measures expert group of the ICDPR (Behrendt H., 2008).

Formulation of spreadsheets

Excel was used for the initial flow calculations. A separate excel workbook was allocated to each country, with a separate sheet allocated to each flow involved. A total of nine processes were included for each country, which were connected by 30 to 35 flows, the calculations for which will be explained next. The processes Agricultural Soils and Animal Breeding were calculated separately in excel but counted as subprocesses of the single process Agriculture when entered into the STAN software for simplicity. Table 1 outlines the complete formulation of processes and flows involved in for each country:

Table 2: **Illustration of all processes and flows calculated for each material flow analysis for Germany, Hungary and Romania.**

Process Agricultural Soils			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Deposition		NH3 emissions (N only)	
N-fixation (N only)		Denitrification (N only)	
Extra from WWM		Feedstuffs from Ag soils	
Mineral Fertilizer		Plant Products	
Manure		Erosion to SW	
Leftovers		Overland Flow	
		Ag groundwater	
Change in stock (P only)			

Process Animal Breeding			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Feedstuffs from industry		NH3 emissions (N only)	
Feedstuffs from Agriculture		Meat & animal products	
		Manure	
		Leftovers	

[6] http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes : Accessed on May16th, 2009

Process Industry			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Plant products		Feedstuffs	
Meat & animal products		Consumption of mineral fertilizer	
Mineral fertilizer imports		Waste & wastewater	
Plant & animal imports		Household consumption	
Mineral fertilizer production		Plant & animal exports	

Process Waste Management			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Household waste		Flow of treated wastewater	
Industry Waste		Sludge to agricultural soils	
Household wastewater		Urban systems	
Industry wastewater		Denitrification (N only)	
Change in stock (P & N)			

Process Household			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Household plant consumption		Household waste	
Household animal consumption		Household wastewater	

Process Surface water			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Urban systems		Load to Danube corridor	
Agricultural soil erosion		Denitrification (N only)	
Overland Flow			
Flow of treated wastewater			
Percolation from groundwater			
Atmospheric deposition			
Runoff from other soils			
Change in stock (P only)			

Process Groundwater			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Agricultural Groundwater		Percolation to surfacewater	
Percolation from other soils		Denitrification (N only)	

Process Other Soils			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Deposition		Percolation to groundwater	
		Runoff to surface water	
		Denitrification (N only)	
Change in stock (P only)			

Process Danube Corridor			
INPUT FLOWS	**Average**	**OUTPUT FLOWS**	**Average**
Load to Danube Corridor		Load to the Black Sea	
		Denitrification (N only)	
Change in stock (P only)			

It should be noted that for Phosphorus, the processes Soils, waste management, surface water and Danube corridor were balanced by adding a change in stock. For nitrogen, processes soils were balanced through the percolation to groundwater flow and in all others (waste management, surface water, Danube Corridor) through denitrification.

Following the calculation of these values, which will be described next, these processes and flow values were entered into the STAN software in order to illustrate each country material flow analysis as a whole as follows (Figure 6):

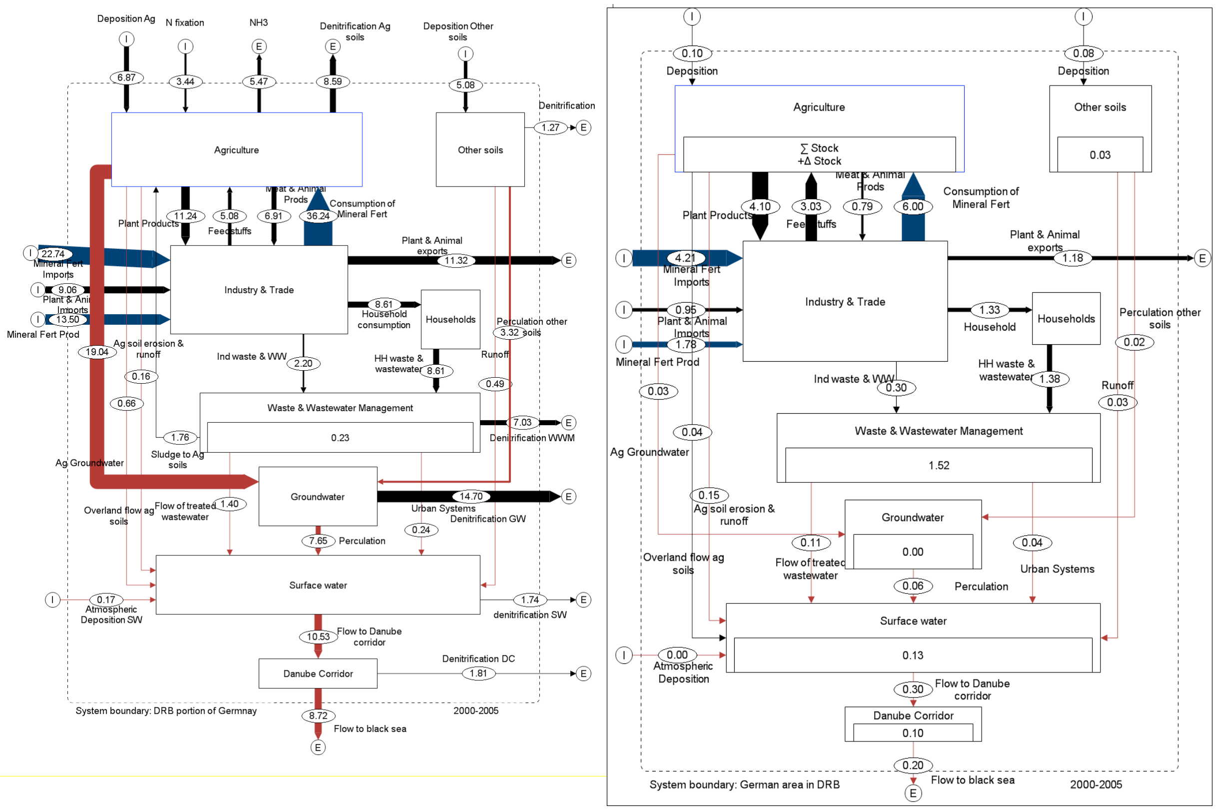


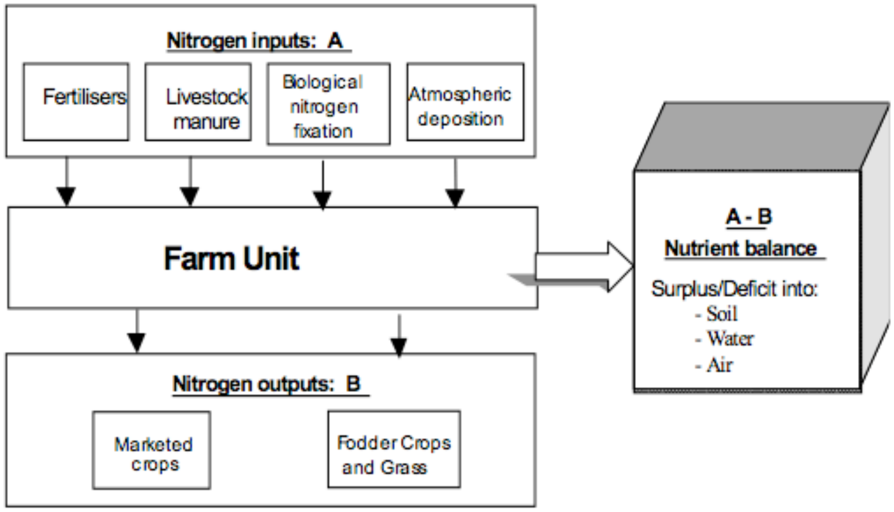
Figure 6: **Schematic of Material Flow analysis using the STAN software including all flows and processes used for this study for Nitrogen (left) and Phosphorus (right).**

Processes & Flows

Processes, for the purpose of this study were defined as the transport, transformation or storage of the nutrients nitrogen and phosphorus. All agricultural processes were considered in the MFA for each country, as well as all processes receiving the flows coming from these agricultural processes. These processes will now be listed and explained along with all flows connected to these process that were considered for this study:

Agricultural soils

All nutrient inputs and outputs were included in the agricultural soils process according to the OECD method illustrated in Figure 7:



Source: OECD (2001), *Environmental Indicators for Agriculture — Volume 3: Methods and Results*, Publications Service, Paris, France

Figure 7: **The main elements in the gross nitrogen balance calculation of the OECD method used to calculate the subprocess agricultural soils as part of the material flow analyses within this study (OECD, 2001).**

They are listed next and explained:

- Deposition: This included the atmospheric deposition of both nitrogen and phosphorus onto agricultural soils only. The following values were used for each country:
  - Germany: 20 Kg N/(ha.yr)
  - Hungary: 10-15 Kg N/(ha.yr)
  - Romania: 10 Kg N/(ha.yr)

- Nitrogen fixation: This was calculated in tonnes of N/year from all leguminous plants in each country using nitrogen coefficients from Krioss et al, 1998 as follows:

*Average Ha taken up by legumes in question * N-fixation coefficient (kgN/Ha)*

- Mineral Fertilizer: These values were obtainable directly from the database in tonnes of nutrients per year and were directly entered into the excel sheet as such.

- Manure: For this value the quantity of livestock for each country was downloaded and entered into excel. Manure coefficients (GVE schlüssel) taken from Kroiss et al (1998) were assigned to each quantity in the following manner:

*((1000's of animal head * manure coefficient (GVE Schlüssel)) * (kg N/GVE/year))*

- NH3 emissions: This was also calculated based on the livestock values obtained from the database. They were calculated as follows:

*Kg N/animal/yr * # of animal head per year*

Volotisation of nitrogen is a result of the conversion of nitrogenous matter to NO, N_2O or Ammonia (NH_3), and is dependent upon pH value. These processes tend to occur in the stable, during manure storage or whilst spreading manure onto the soil. Due to the huge pollution problem associated with this phenomenon, and eventual deposition to other remote soils and surface waters causing a eutrophication risk, these emissions must be included in the calculations to avoid any missing data.

- Denitrification: This was calculated using a predetermined value for agricultural soils. Denitrification is the final stage where nitrate is converted into gaseous nitrogen. This process takes place with the participation of heterotrophic bacteria. The product can either end up being gaseous nitrogen (N_2) or nitrous oxide (N_2O). Both are emitted into the atmosphere, however only N_2O is considered a greenhouse gas and polluting to the atmosphere. N_2 is the main part of air and a neutral product with no adverse effects to the environment. At the moment only rough estimations exist regarding what percentage of the emissions resulting from denitrification go to N_2O and N_2, which is why they also should be included in these calculations but the results should be analysed carefully, taking this process into account.

  The following values were used for each country:
    - Germany: 25 kg N/(ha.yr)

  - Hungary: 17 kg N/(ha.yr)
  - Romania: 8 kg N/(ha.yr)

- Feedstuffs, plant products: The yield, area harvested and production quantity for each plant product was arranged in the appropriate sheet and the nitrogen content was assigned for each one. Nitrogen content values all came from the Bayerische Landesanstalt fur Landwirtschaft (2008), and multiplied with the yield and area harvested values in order to calculate nitrogen removed.

- Percolation to groundwater, overland flow, tile drainage, and erosion: MONERIS values were obtained and entered for each of these values (Behrendt H., 2008). The MONERIS model and the method used to adapt these values to the material flow analysis will be explained once all processes and flows are described.

Animal breeding

The feedstuff, NH_3 emission and manure flows were all calculated as described above. This leaves meat and animal products, which were calculated in the following fashion:

A nitrogen coefficient was obtained from the same source of Kroiss et al, 1998 and applied to all meat and animal products produced. It was assumed that 2/3 of the NH_3 emissions were emitted during the animal breeding stage and storage processes and the remaining 1/3 were emitted during the spreading of manure on arable cropland.

Industry

This included all flows coming from and going to agriculture. This included:

- Feedstuffs industry: These values were also obtained from the databases and the nitrogen content was calculated using the method described above for plant products and feedstuffs from agricultural soils. As neither database provided exact quantities of feedstuffs coming directly from industry, the total feedstuff availability was calculated instead and was subtracted from the total availability as it was assumed that what didn't come directly form agricultural soils came from some part of industry in each country.

- Mineral fertilizer imports & exports: These values were also obtainable straight from the database in the form of tonnes of nutrients.
- Plant and animal imports: These were downloaded as tonnes of products and then the nitrogen content was calculated in the same manner as with plant products (described above).
- Mineral fertilizer production: This value was treated as an import into the industry process and calculated by subtracting the mineral fertilizer imports value from the mineral fertilizer consumed value.
- Household consumption: again, the amount that each country consumed in the form of tonnes of plants and animal was obtained from the database and transformed into tonnes of nutrients using the same nitrogen and phosphorus coefficients. A loss coefficient was applied to consumed products as needed and accounted for losses through product cultivation and production.
- Waste & wastewater: will be explained next.

Waste & Wastewater management

The input flows to this process included the waste and wastewater coming from households and industry. They were calculated as follows:

- Waste: Waste values were a little more complicated to calculate. This is where the details of EUROSTAT became helpful. The generation of solid waste from agriculture and households was available for Hungary however the values for household solid waste was not available for Romania and neither was available for the Danube portion of River Basin in Germany. So, assumptions were made for these values. The household waste value was calculated by calculating all the values for the household process (described next) and then using the missing waste value to balance the process. Where it was missing, the waste for industry was calculated by balancing the waste management process.

- Wastewater: The standard value of 4 kg nitrogen/ca/yr for household wastewater was used for all three countries. The nitrogen wastewater values for industry used were as follows:

  - Germany: 2 kg N/(ca.yr)
  - Hungary: 1kg N/(ca.yr)
  - Romania: 0,5 kg N/(ca.yr)

- For phosphorus wastewater values, 0,5 kg/(ca.yr) was applied to all three countries for both industry and households.
- For the outputs flows, the MONERIS values were used for the 'flow of treated wastewater' and 'urban system' flows (described next). It was then assumed that of the remaining wastewater output, 80% went to denitrification and 20% went to sludge applied to agricultural soils.
- The whole process of waste management was balanced by adding a stock of nutrients both for nitrogen and phosphorus.

Household

Both input and outputs flows for this process were explained above. The only difference lies with the addition of detergents for all phosphorus household processes. This was treated as an import form outside the system. The following values were used for each country:

- Germany: 0.2 g P/ca/day
- Hungary: 0.8 g P/ca/day
- Romania: 0.6 g P/ca/day

MONERIS

The processes surface water; groundwater, other soils and Danube Corridor and their flows were all calculated using the MONERIS model:

The MONERIS model, used in the final stages of the material flow analysis of this thesis is based on a multitude of input data regarding the natural system and anthropological activities of the Danube River Basin. Factors included in this model are:

- Soil map.
- Meteorological data.
- Land use map.
- Population, degree of urbanisation, specific emissions of N and P.
- Connection to sewer systems and degree of waste water treatment.
- Nitrogen surplus on agricultural soils, influenced by livestock density, fertilizer use, efficiency of agricultural practice.
- Phosphorus accumulation in soils
- Erosion, optionally under influence of erosion abatement practices.
- Atmospheric deposition.

In order for the MONERIS model (Behrendt et al., 2008) to calculate emissions of nitrogen and phosphorus into surface water uses the above information through semi empirical formulas. Seven different pathways are distinguished: (1) point sources (wastewater treatment plants, industry, and agro industry), (2) overland flow (3) ground water flow (4) Tile drainage (5) erosion (6) diffuse emissions form urban systems and (7) atmospheric deposition. Changes in soils lead to changes in the retardation processes involved in nitrogen percolation, which can amount to years up to several decades. These changes and or storage processes are also quantified through empirical formulas inside MONERIS.

The MONERIS model can be illustrated through a schematization of the 388 sub catchments in the Danube watershed. Each sub catchment is about 2000m^3 (Figure 8)

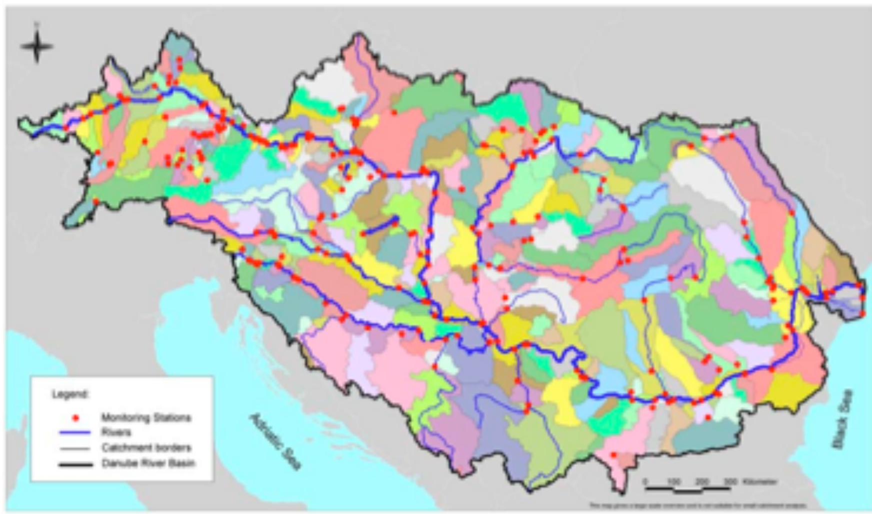


Figure 8: **Overview of the schematisation of the Danube Basin in MONERIS (Kroiss et al, 2005).**

The various flows that MONERIS is able to calculate helps to clarify the fate of nitrogen and phosphorus in the Danube River Basin. It calculates the retention and denitrification rates, which allows for the opportunity to compare between calculated loads to surface waters and to the Black Sea (emission minus retention) versus measured loads (river water flow multiplied by stream concentrations).

MONERIS flows

The remaining values were taken from the MONERIS model, which is run by the Pressures and Measures expert group from the International Commission for Protection of the Danube River (ICPDR) (Beherendt, 2008)[7]. The flows taken from this model are described below along with an explanation as to what flow they represent in this model:

- Atmospheric deposition: It was assumed that all deposition ended up in the surface water process and stemmed from outside the system.

[7] Behrendt H. (2008) MONERIS calculations for PM-EG of ICPDR, version 2.02

- Overland flow: This was calculated by hectare and split as a runoff flow (including direct runoff of manure and urea) between agricultural soils and other soils to the surface water process.
- Tile drainage: It was assumed that this all came from agricultural soils to surface water.
- Erosion: Again all nitrogen from erosion was assumed to have originated in agricultural soils and ended up in the surface water.
- Groundwater: This flow was split between the agricultural soils and other soils processes, and calculated as the surplus Nitrogen in each of these processes ending up in the groundwater process. For Phosphorus, the MONERIS values were used directly and any surplus was attributed to a change in stock in soils.
- WWTP (Waste Water Treatment Plants): this flow originated in the waste management process, ending up in the surface water.
- Urban systems: This flow originates from urban waste systems which included the sum of emissions from septic tanks, sewer systems without treatment, combined sewer overflows and inputs via rainwater sewers. This was treated as a separate flow from waste Management to surface water.

Phosphorus

The above methodology was also applied also to the phosphorus balance. Obviously denitrification and nitrogen fixation are not an issue for phosphorus. The only difference in the process of eventually balancing each process was that for the agricultural soils, surface water, Danube Corridor, other soils and waste management processes, all leftover phosphorus was attributed to a change in stock.

Special case: Germany

Germany was a special case for a material flow analysis and nutrient flow balance as only a small portion of it is contained in the Danube River Basin. In this case the values for Baden-Württemberg and Bayern were taken from the EUROSTAT database where ever possible. As only livestock and crop values were available for this area of Germany, the remainder of the flows were calculated for all of Germany, and the correct proportion for the Danube Basin portion of Germany was then calculated. For example, feedstuff values from all of Germany's harvest were calculated and then divided by the population of the Danube river basin (DRB) portion of Germany for per capita/year values, and divided by the area of this same region for per hectare/year values. For total emission values, these same kg per hectare/year values were multiplied by the area of the DRB portion of Germany, then divided by 1000 to come to the tonnes/year value. All other flows were calculated in the same fashion, except for the MONERIS values, which were values for the DRB portion of Germany already in tonnes/year, and were translated directly from here into hectare/year and capita/year values.

Balancing of the system

The final values were entered in the form of tonnes per year in a table similar to that of Table 2. These core values were then translated into kilograms per capita/year and kilograms per hectare/year. As the MONERIS model values were given as Kilograms/hectare/year, these values were first entered and then multiplied by the total area, then balanced in this table and then converted into kilograms per capita and kg per hectare. All population and area values were taken straight from EUROSTAT.

When balancing the Agricultural soils and Industry processes and before applying the MONERIS model, several assumptions had to be made. For the sub process animal breeding, when balancing the feedstuff inputs with the outputs manure, NH_3 emissions and meat and animal products there was occasionally a deficit in the output calculations. It was assumed for all countries that this deficit could be attributed to the 'leftovers' that accumulate during the animal breeding process, such as meat and fodder leftovers and scraps. It was assumed that this leftover flow was applied directly back onto agricultural soils and was therefore treated as a flow from animal breeding to agricultural soils.

For the balancing of the Industry process, again if there was a deficit it tended always towards the output column. As was explained earlier, the feedstuffs from industry flow were estimated from all the other data available in the database, as the exact data itself was not available. It was therefore assumed in this case that this flow was underestimated and the remainder of the balance was added here. This worked well for the Hungary balance; however there were a few more difficulties in balancing Romania and Germany, the solution of which will be discussed next.

The data for Romania was lacking in some areas, causing problems with the final balance of both nitrogen and phosphorus. At closer observation, the balance of livestock inputs and outputs was clearly missing important data. The sum of nitrogen exiting the animal breeding process was significantly more than that entering it. In order to balance this correctly, the manure and NH_3 values were averaged down to match the inputs of feedstuffs. As standard manure coefficients were used all the way through this project, it was assumed that the nutrient turnover of animals in Romania as an average is lower than that of a German animal.

For the balancing of the waste management process, more assumptions had to be made for solid waste. In particular solid waste values for Romania were not available from either database and so were balanced from the remainder of this process, which was readily available.

Balance of MONERIS values

The MONERIS values were obtained and inserted into the system as described above. This consisted of transforming the values, which represented the output from all soils in the country into total values, and per capita values. The following formula was applied to each MONERIS value:

M (Kg/Ha*yr) * total area of each country

These values were inserted into their respective flows, as described earlier in the MONERIS section of the methodology. A few additional adjustments were made for the final system balance:

1. The remainder/balance of the output from the process 'agricultural soils' was attributed to percolation into the groundwater process for nitrogen. For phosphorus it was assumed that this remainder ended up in soils as a change in stock.
2. In order to balance the processes of other soils, the Danube Corridor and surface waters the balance in the output columns was attributed to denitrification in the case of nitrogen balance and to a change in stock in soil/water in the case of the phosphorus balance.
3. Nitrogen in the groundwater process was balanced through denitrification. For phosphorus, only the MONERIS values were taken for the percolation flows. This left no stock in groundwater – the remainder of phosphorus was balanced in the respective soils processes as a change in stock.

Nutrient Balances

Agriculture

Once the material flow analysis was calculated and balanced, agriculture as a whole was extracted and a farm gate balance was applied to calculate the losses from agriculture for each country. This method to balance nutrients treats the farm as an entity. All nutrients from within the farm are ignored, such as fodder crops, grass, leftovers and manure. The final balance for this study was then calculated as follows for further analysis:

(Deposition + N-fixation + Extras from WWM + Mineral Fertilizer + Feedstuffs from industry)

minus

(Plant products + Meat & animal products)

This was illustrated through the STAN software in the following manner:

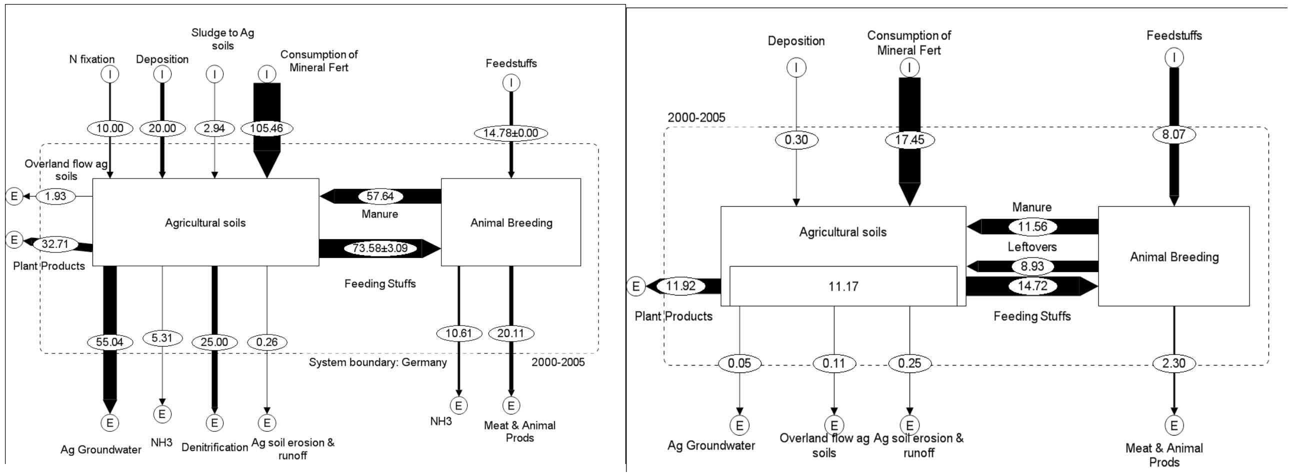


Figure 9: **Schematic of the sub process agriculture using the STAN software (nitrogen on the right, phosphorus on the left).**

Whole country nutrient balance

Similarly, each country as a whole was analysed and total exports from the country material flow analysis were subtracted from the total import of nutrients into the country. Changes in stocks were added as a separate output value. These results were translated into graph form and will be illustrated and explained further in the results chapter.

Other results:

In accordance with the analysis and suggestions of the OECD, indicators should possess the qualities of being easy to understand, easy to compile, compatible with national accounts, and data should be freely available. It is in this context that the balanced Material flow analysis is analysed, the results of which will now be further broken down flow by flow.

RESULTS

Nutrient Processes

As described in the methodology, nitrogen and phosphorus Material Flow analyses were calculated, as well as nutrient balances for the whole of agriculture for Germany, Hungary and Romania for the period 2000-2005. Here the most pertinent country findings and processes influencing emissions into the Danube corridor and into the Black Sea will be discussed. Losses between countries will be illustrated in this section and then discussed in the next chapter.

The whole MFA as well as the Agriculture and surface water balances are illustrated in the annex of this study.

Surface waters

To start with the surface water nutrient balance will be observed for each country. The summary of total nitrogen and phosphorus emissions from surface waters can be observed in Table 3:

Table 3: Summary of total inputs to surface waters by per capita and per hectare of total land area for the Danube portions of Germany, Hungary and Romania.

	Nitrogen		Phosphorus	
	Kg/ca/yr	Kg/ha/yr	Kg/ca/yr	Kg/ha/yr
Germany	11	22	.46	.83
Hungary	4.14	4.5	.65	.71
Romania	6.34	6.18	.63	.58

Inputs into Surface waters

For the period spanning 2000 to 2005, the greatest contribution to the total nitrogen varied between countries. Figures 11-12 illustrate the N/P input ratios for surface water inputs to Germany, Hungary and Romania.

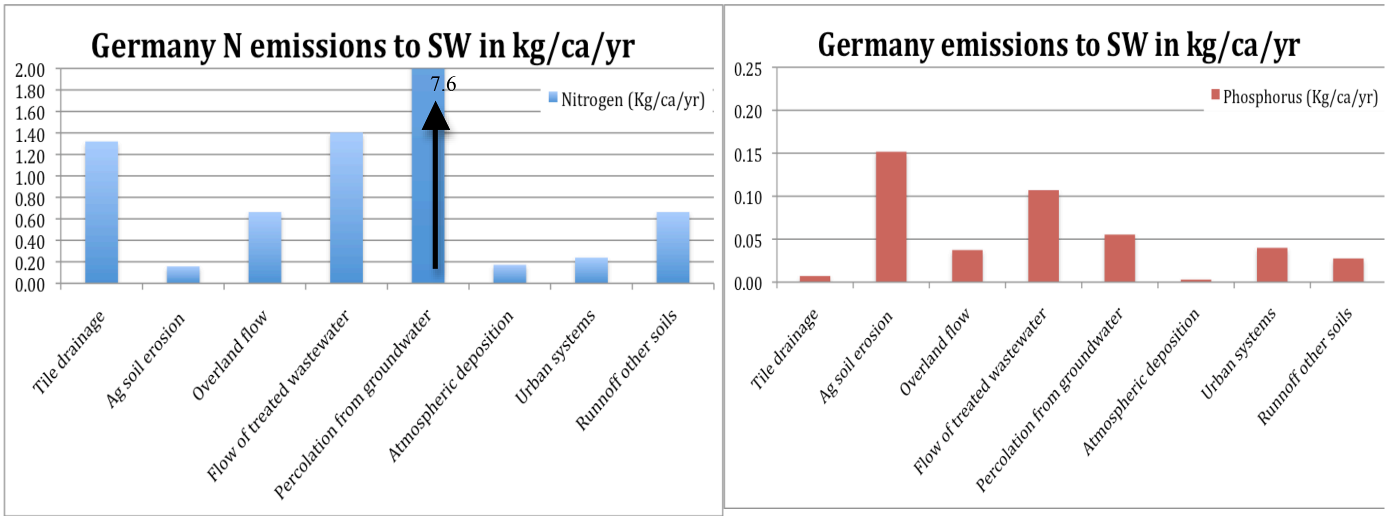


Figure 10: **Calculated sources of nitrogen and phosphorus flows into surface waters per capita and yr for Germany from 2000-2005 (average values). All MONERIS values are taken from Berhendt et al, 2008.**

For Germany, percolation from groundwater was by far the most important pathway for surface water nitrogen and Agricultural soil erosion was the most important phosphorus input, followed closely by wastewater.

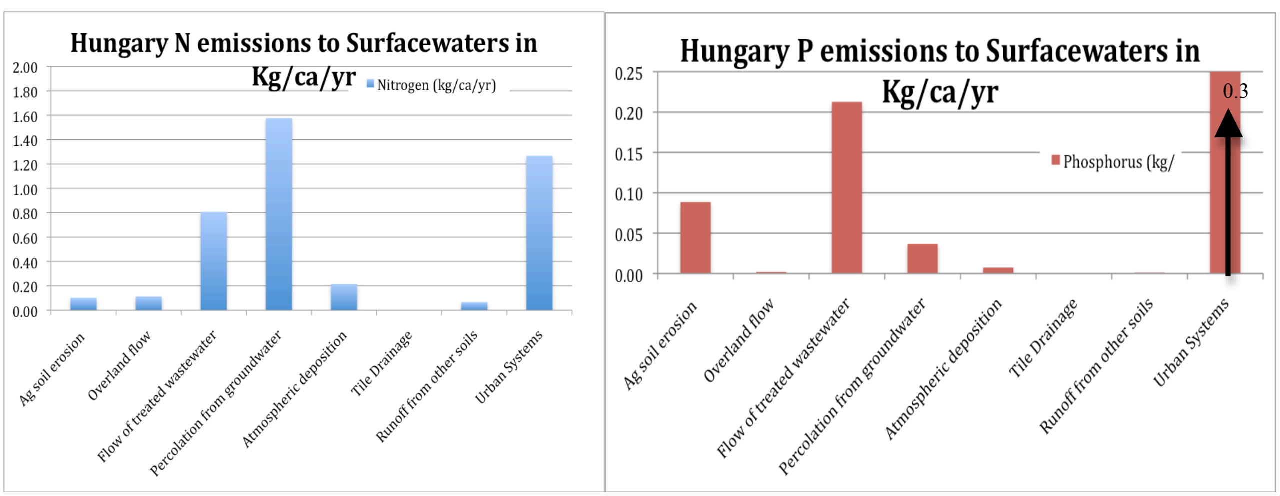


Figure 11: **Calculated sources of nitrogen and phosphorus flows into surface waters per capita and yr for Hungary from 2000-2005 (average values). All MONERIS values are taken from Berhendt et al, 2008.**

Hungary's case was slightly less clear-cut. The most important pathway for nitrogen stemmed from percolation form groundwater, however wastewater flow and urban system combined exceeded groundwater. In the case of phosphorus clearly wastewater and Urban systems contributed most, followed by agricultural soil erosion. More specifically, 19% of surface water N emissions came from treated wastewater and 30% from Urban systems which attributes 49% total to wastewater, whereas percolation from groundwater was a close second at 38% of the total nitrogen surface water input flow. For phosphorus emissions, treated wastewater emitted 33% to surface waters and urban systems emitted 46% for a total of 79% of phosphorus emitted to surface water. At 14%, agricultural soil erosion and runoff came in as the second most important phosphorus flow to surface water for Hungary.

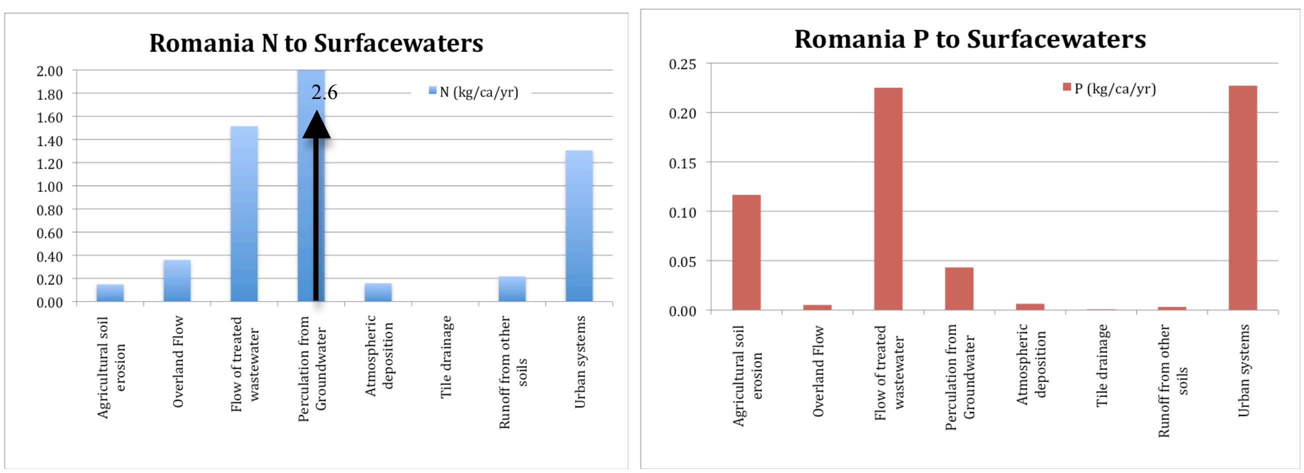


Figure 12: **Calculated sources of nitrogen and phosphorus flows into surface waters per capita and yr for Romania from 2000-2005 (average values).**

For Romania, again the emissions were split for nitrogen. Percolation from groundwater added 41% of total surface water nitrogen input. Wastewater contributed next to surface waters at 20% of total surface water emissions from urban systems and 23% of total surface water emissions from treated wastewater. That's 43% of total surface water emissions from wastewater. For phosphorus emissions to surface water, 36% were emitted from urban systems and treated wastewater totalling 72% of total surface water emissions overall, followed by agricultural soil erosion at 19%.

So for surface water emissions for all three countries both wastewater and percolation from groundwater were the leading flows for nitrogen. For phosphorus the leading diffuse flow of nutrients came from erosion, keeping in mind that wastewater led in Romania and Hungary.

Total emissions are illustrated in figure 14:

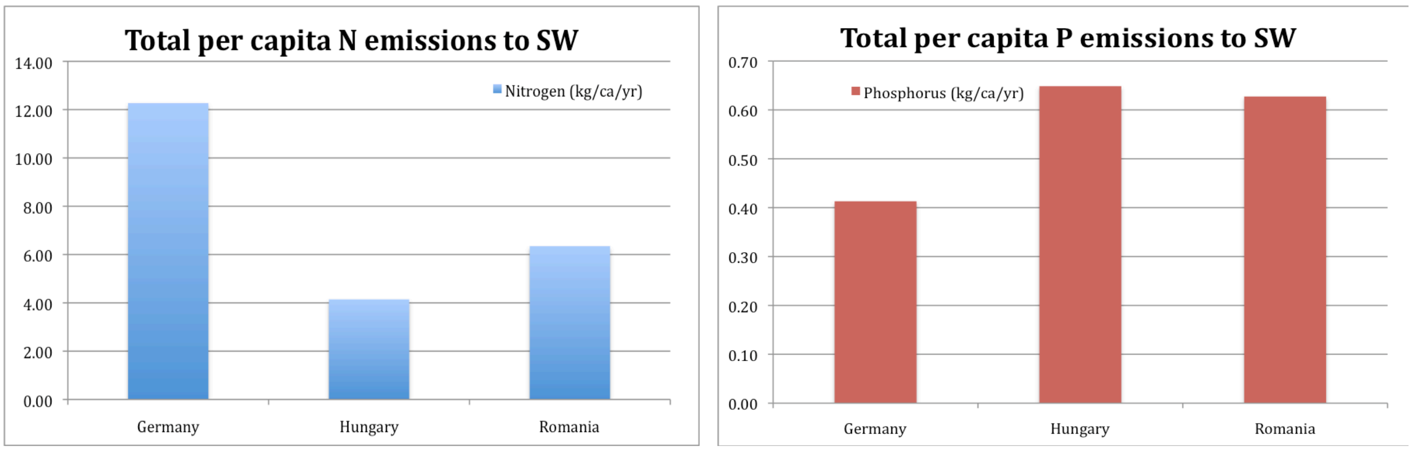


Figure 13: **Total nitrogen and phosphorus emissions to surface water per capita and yr for all three countries from 2000 to 2005.**

At 12.3 kg/ca of nitrogen a year, Germany is by far the highest emitter of nitrogen emissions, followed by Romania at 6.3 kg per ca and year. For phosphorus emissions, Hungary was the highest emitter, followed by Romania and then Germany.

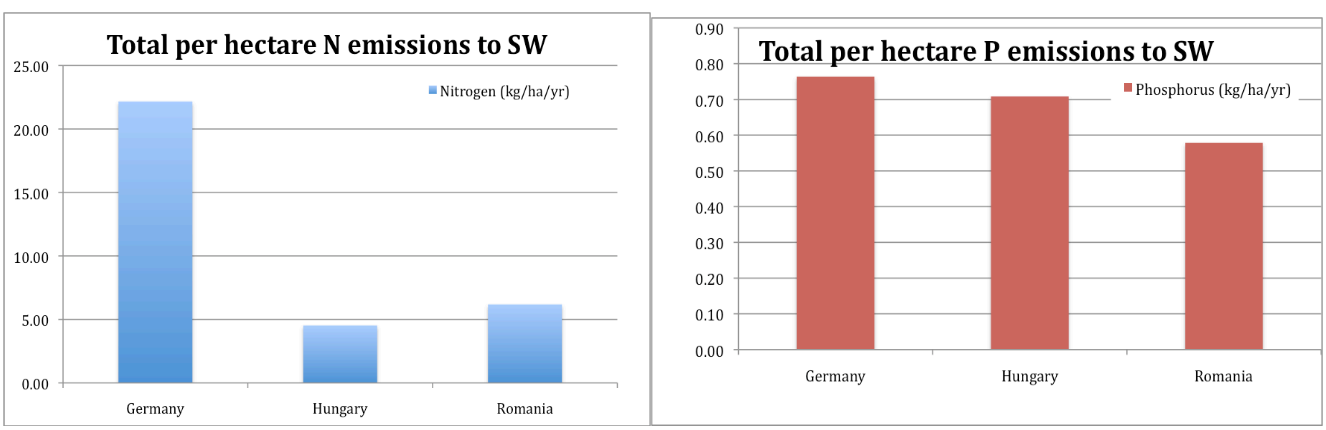


Figure 14: **Total nitrogen and phosphorus emissions to surface water per hectare and yr (total area) for all three countries from 2000 to 2005.**

For per total area hectare emissions, Germany emits the most nitrogen with 22 kg per hectare and yr followed by Romania at 6.2 kg N per hectare and yr and Hungary came last with 4.5 kg nitrogen per hectare and yr. For phosphorus emissions Germany led with 0.76 kg P/(ha.yr) followed by Hungary at 0.71 kg P/(ha.yr) and Romania emitted the least phosphorus at 0.58 kg P/(ha.yr).

So to summarize, groundwater and wastewater contribute the most to surface water emissions for N, a large proportion of which comes from agricultural soil percolation for groundwater emissions. For Phosphorus emissions, after wastewater, soil erosion from agricultural soils contributed significantly to total diffuse surface water emissions. As far as total N emissions are concerned, Germany is the highest emitter followed by Romania then Hungary. For phosphorus, Hungary is the highest emitter per capita and year followed by Romania then Germany. For per hectare and yr P, Germany emits the most P followed by Hungary and finally Romania.

Groundwater

As groundwater played an important role in contributing to the final surface water input flows for nitrogen, it is logical to next analyse the groundwater process, country by country. The main input flow of nitrogen into groundwater came from percolation from agricultural soils and other soils, whereas the predominant diffuse phosphorus flow came from erosion of agricultural soils.

The output flows from groundwater consisted of percolation to surface water and denitrification for nitrogen flows. This last flow varied considerably between countries. Germany for example lost 66% of its groundwater flow to denitrification, whereas Hungary lost 92% and Romania only 40%. As so little is known to date about the specific dynamics of the denitrification process, this flow was estimated by using it to balance out all the other flows in the groundwater process once they were known. It is assumed that the natural conditions of each country can explain this variation.

Wastewater Management

The second most important flow into surface waters carry on from wastewater management, split as illustrated in Table 4:

Nutrient removal efficiency for waste water is described in Table 4. Germany's nutrient removal through waste water management was the most efficient at 73-74% for both phosphorus and nitrogen. Romania came second for phosphorus at around 85% but last for nitrogen at 37% and finally Hungary's nutrient removal efficiency came in at around 49%-59% It must be noted however that these figures only measure waste that actually made it to the waste management systems. Whereas Germany's population is almost completely connected to waste water management systems, only 50% of Romania's population is connected up to the present. It is not known where the rest of sewage goes, none of which is treated. Considering that this study is only focussing on the waste coming from agriculture this does not affect this study to such a degree: all the excess nitrogen and phosphorus is reapplied to it's soils. There still needs to be a more detailed investigation on this matter regarding future studies in this source of pollution however.

Table 4: **Nutrient removal or retention for Wastewater connected to wastewater management in Germany, Hungary and Romania between 2000-2005.**

	Nitrogen	**Phosphorus**
Germany	73%	74%
Hungary	59%	49%
Romania	37%	61%

Agricultural soils

For this section nitrogen and phosphorus will be discussed in separate sections to avoid any confusion.

Nitrogen:

Figure 15 and Figure 16 illustrate the total flow of nitrogen through agricultural soils. Mineral fertilizer and manure take up the majority of the input flows, mostly mineral fertilizer for Germany and Hungary but 50% manure/50% mineral fertilizer for Romania. The output flows are primarily contained in feedstuffs and plant products, followed by a large proportion going to percolation to groundwater for Germany and then Hungary. Only 1.33 kg N /Ha/yr went to groundwater for Romania compared to 55 and 27 kg/Ha/yr for Germany and Hungary respectively. Hungary shared plant products and feedstuffs by 50% each, however Germany produced 74 kg N/ha/yr of feedstuffs versus 33kg/ha/yr of plant products. Germany's meat production and exports is fairly high also which explains this, and will be discussed in more detail in the discussion chapter. Romania committed slightly more land area and therefore nitrogen to feedstuffs.

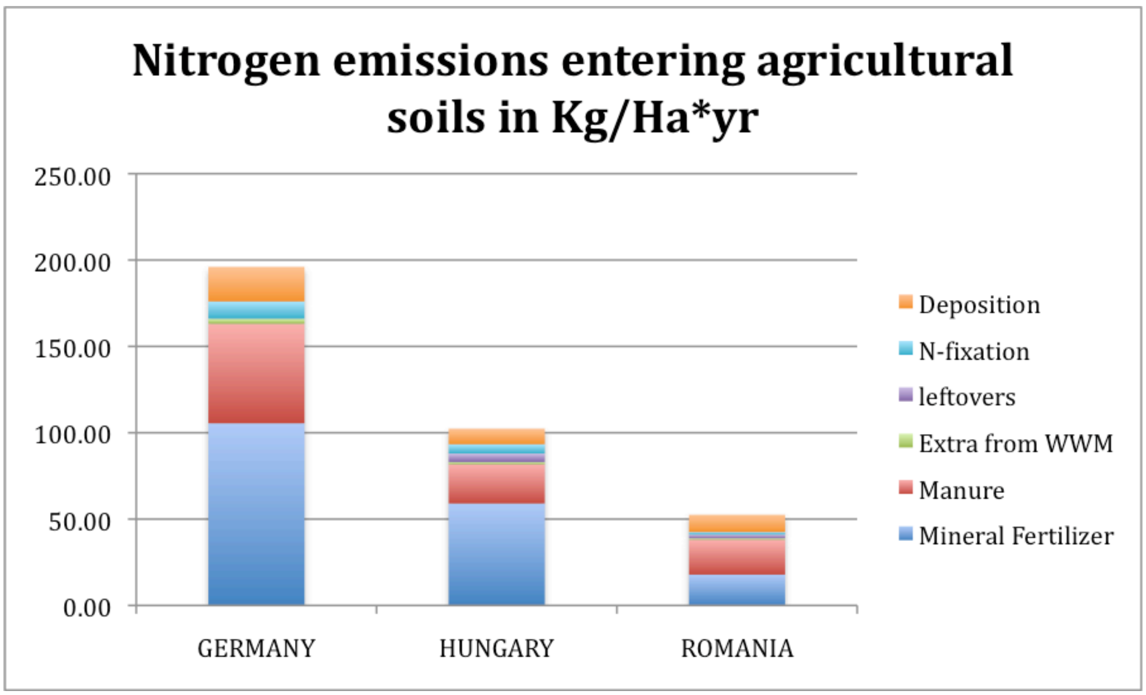


Figure 15: **Total nitrogen input flows into agricultural soils per agricultural area for Germany, Hungary and Romania. Averaged values from 2000-2005.**

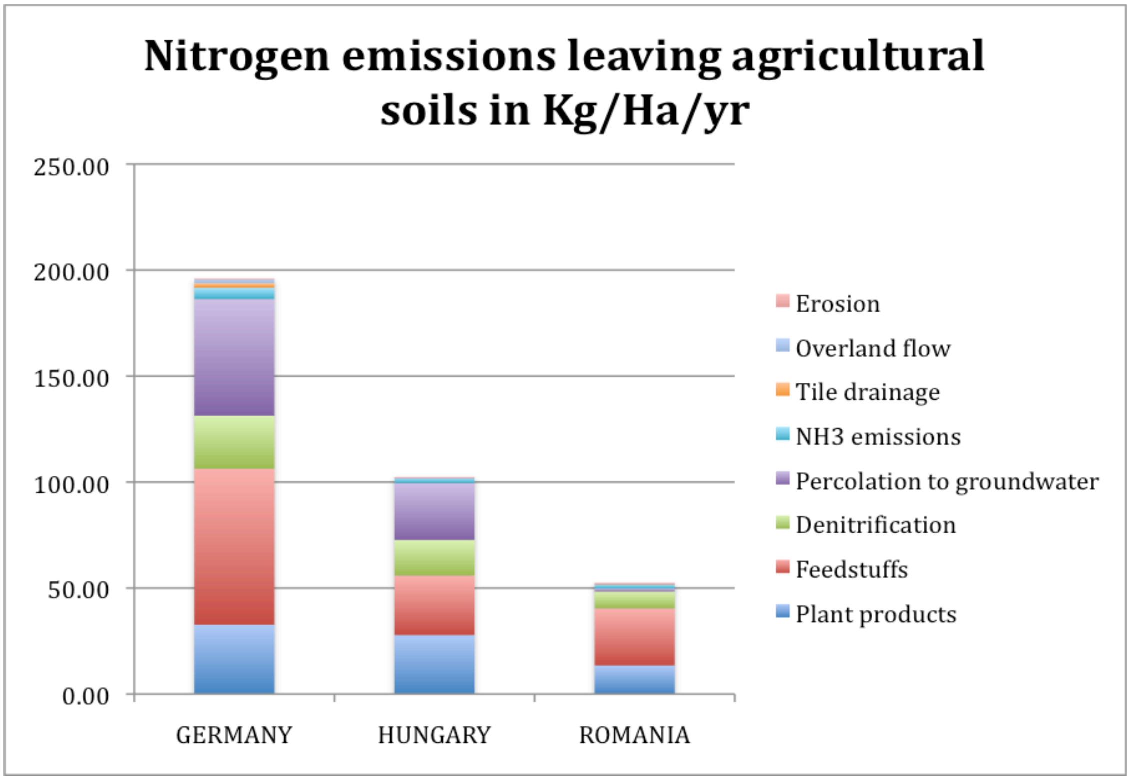


Figure 16: **Total nitrogen output flows into agricultural soils per agricultural area and yr for Germany, Hungary and Romania. Averaged values from 2000-2005.**

Phosphorus

Phosphorus flows to and from agricultural soils are illustrated in Figure 17 and Figure 18. Again, mineral fertilizer dominates the input flows for Germany and Hungary, which was followed closely by the application of manure for Germany. Romania's inputs however are dominated by manure, followed by a smaller fraction of mineral fertilizer. For output flows, feedstuffs dominate flows for Germany and Romania but less so for Hungary.

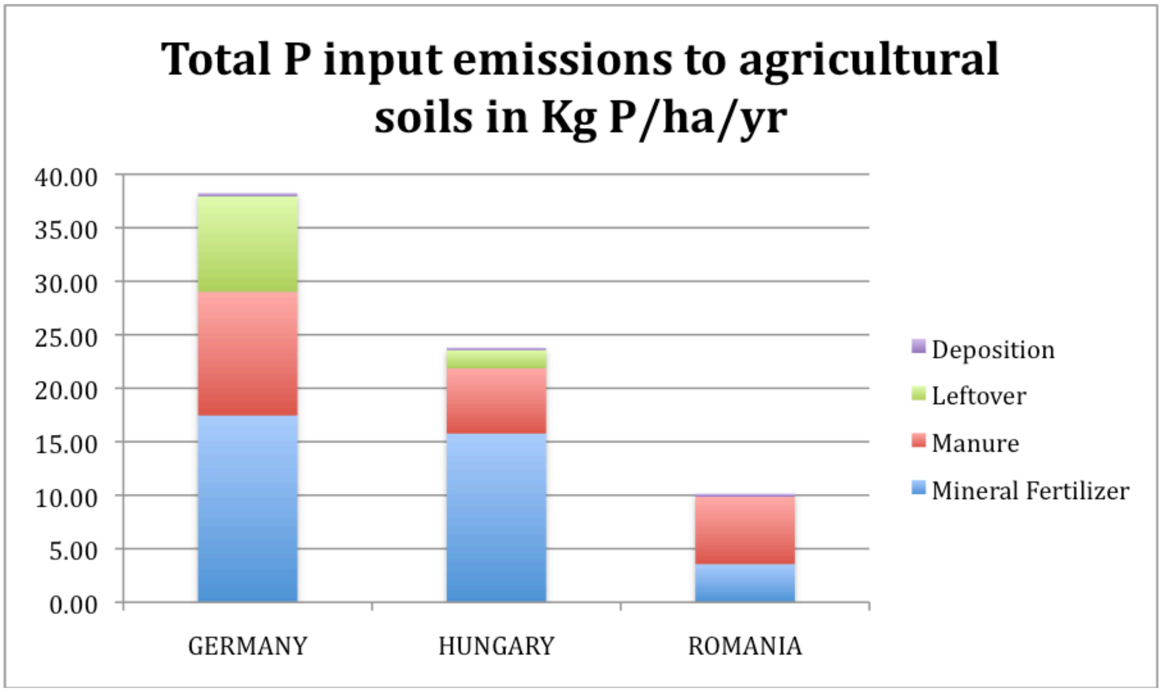


Figure 17: **Total phosphorus input flows into agricultural soils per agricultural area and yr for Germany, Hungary and Romania. Averaged values from 2000-2005.**

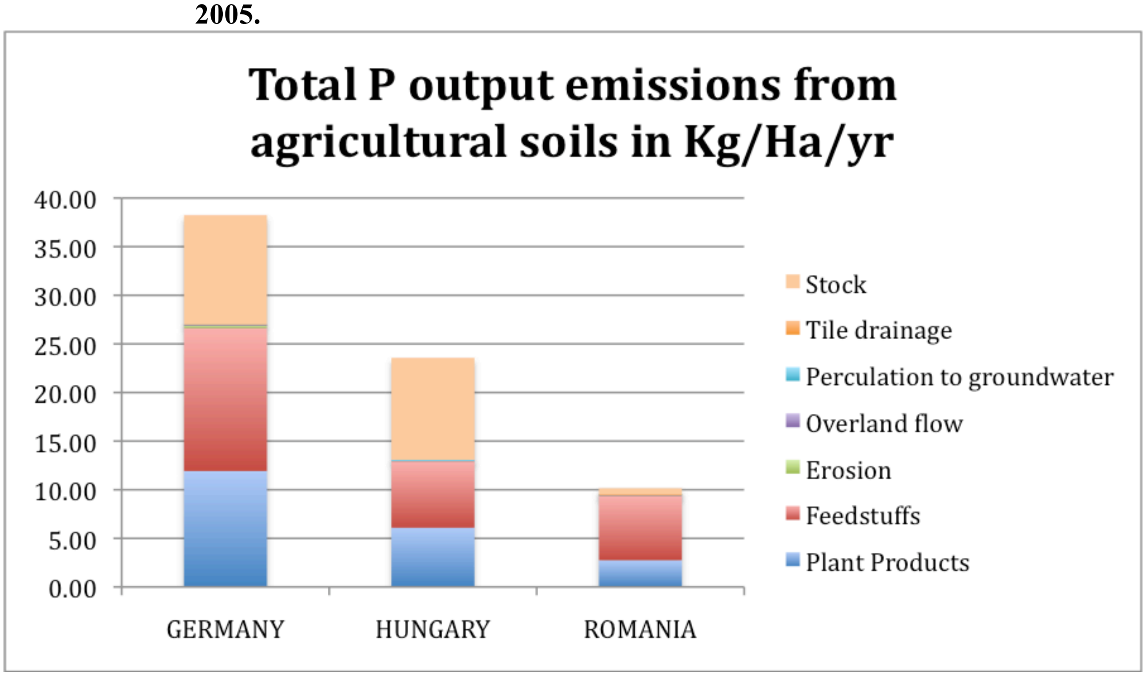


Figure 18: **Total phosphorus output flows from agricultural soils per agricultural area and yr for Germany, Hungary and Romania. Averaged values from 2000-2005.**

Agriculture as a whole

Looking at agriculture as a whole, the comparison of nitrogen losses versus nitrogen contained in anthropogenic products applied is interesting. Per hectare the ‘excess’ nitrogen is obvious for Germany and Hungary and almost non-existent for Romania (Figure 19 & 20). Note the much higher production of meat and animal products in Germany.

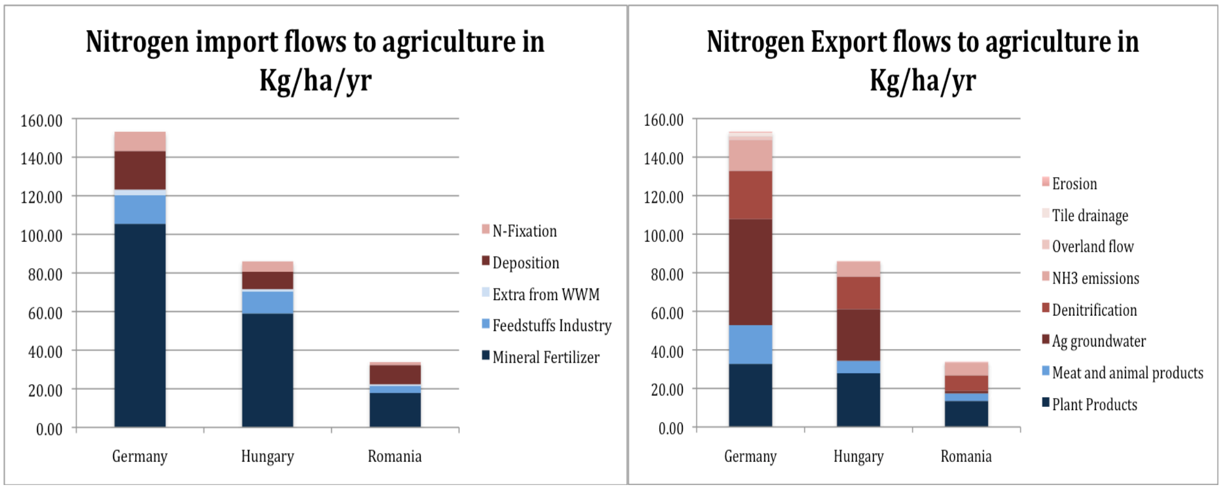


Figure 19: **Graphs comparing total import and exports of nitrogen per hectare and year into the agricultural system boundary (see annex) Blue: anthropological flows, Red: natural flows.**

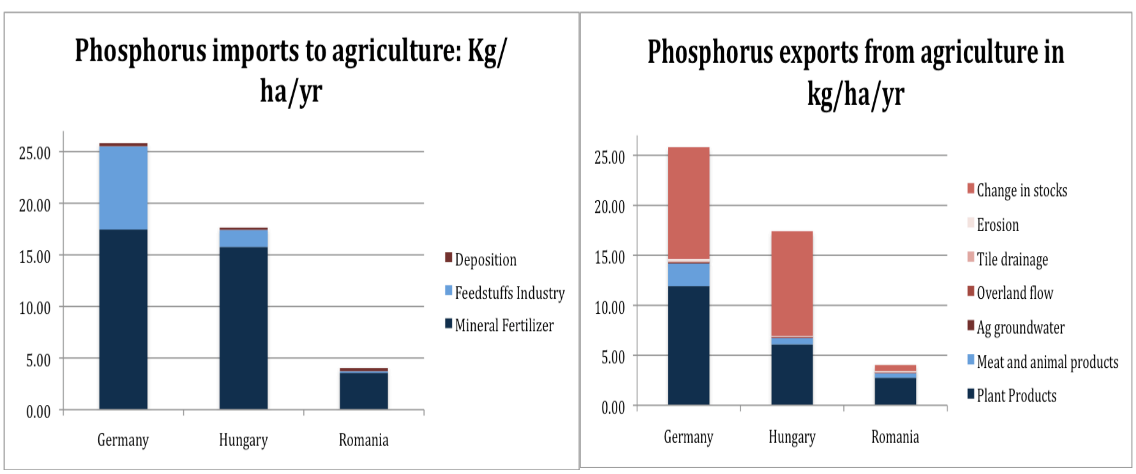


Figure 20: **Graphs comparing total imports and exports of phosphorus per hectare and year into the agricultural system boundary (see annex) Dark blue: anthropological flows, Red: natural flows.**

Nutrient balance of agriculture as a whole was calculated as follows and is illustrated in Table 5:

(Deposition + N-fixation + Extras from WWM + Mineral Fertilizer + Feedstuffs from industry) ***minus*** *(Plant products + Meat & animal products)*

Table 5: **Nitrogen and phosphorus balance of the agriculture process as a whole for Germany, Hungary and Romania**

	Nitrogen		Phosphorus	
	Kg /ca/yr	Kg /ha/yr	Kg /ca/yr	Kg /ha/yr
Germany	35	100	4	12
Hungary	30	52	6	11
Romania	12	16	.5	.7

The surplus including anthropogenic activities only was calculated as follows and is illustrated in Table 6:

(Sludge from WWM + Mineral Fertilizer + Feedstuffs from industry) ***minus*** *(Plant products + Meat & animal products)*

Table 6: **Surplus nitrogen and phosphorus as calculated by applied anthropological products minus the export flows plant products and meat and animal products from agriculture as a whole.**

	Nitrogen		Phosphorus	
	Kg per ha/yr	Kg per ca/yr	Kg per ha/yr	Kg per ca/yr
Germany	70	25	11	4
Hungary	37	22	11	6
Romania	5	4	0.4	0.3

For nitrogen, the surplus values move down from Germany to Hungary to Romania. Phosphorus surplus was equal per hectare for Germany and Hungary (and even higher for Hungary when natural processes were taken into account (Table 5) and negative for Romania. Per capita and yr Hungary looses slightly more phosphorus than Germany. Having recorded these surplus values, it would be interesting to look at plant and animal productivity amongst countries to observe whether an increase in nutrient surplus equals to a corresponding increase in plant and animal productivity.

Table 7: Plant productivity (feedstuffs from ag soils + plant prods) in nutrients per hectare and yr and per capita and yr for Germany, Hungary and Romania between 2000-2005.

	Nitrogen		Phosphorus	
	Kg/ca/yr	Kg/ha/yr	Kg/ca/yr	Kg/ha/yr
Germany	36	106	9	26
Hungary	32	56	7.5	13
Romania	27	40	6	9

Table 8: Meat and animal products productivity in nutrients per hectare and yr and per capita and yr for Germany, Hungary and Romania between 2000-2005.

	Nitrogen		Phosphorus	
	Kg/ca/yr	Kg/ha/yr	Kg/ca/yr	Kg/ha/yr
Germany	7	20	0.79	2.3
Hungary	4	6.5	0.41	0.71
Romania	2.6	4	0.36	0.54

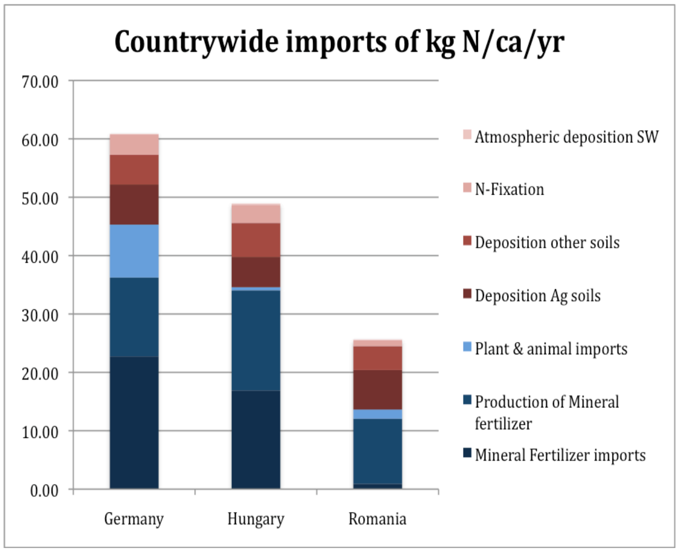
Plant and animal productivity was lowest for Romania, more so per capita than per hectare. For nitrogen Germany produces twice as much plants per hectare compared to Hungary, most likely due to Germany's higher population density and livestock quantities (Table 8). Phosphorus per hectare/year in Germany is most productive, followed by Hungary and finally Romania. For per capita and year phosphorus, the same can be observed but to a lesser degree.

Industry

The main player in the industry process is the imports, production and eventual consumption of mineral fertilizer onto agricultural soils. This input is even more important to the contribution of nitrogen and phosphorus to surface waters except for the case of Romania, where manure predominates as the main provider of nutrients. The proportion of inputs via mineral fertilizer can be seen in figures 15 and 17.

Country wide Nutrient balance

To finalize the results chapter, an analysis and presentation of countrywide balances will be made.



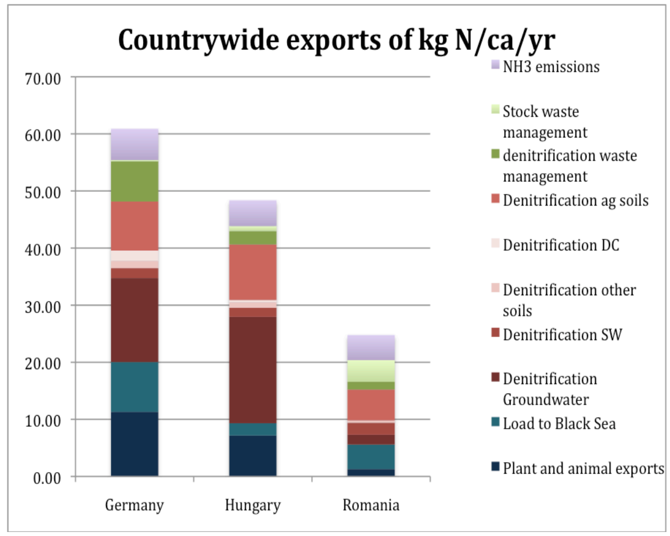


Figure 21: Countrywide imports and exports of nitrogen flows per capita and year for Germany, Hungary and Romania from 2000-2005.

The countrywide balance of nitrogen imports shows comparatively the same amount of mineral fertilizer consumption between Hungary and Germany. Germany, however imports much more plant and animal products and mineral fertilizer compared to Hungary and Romania. The nitrogen exports graph shows that Germany also exports more than Hungary and Romania. Romania imports and exports very little in comparison to Germany and Hungary.

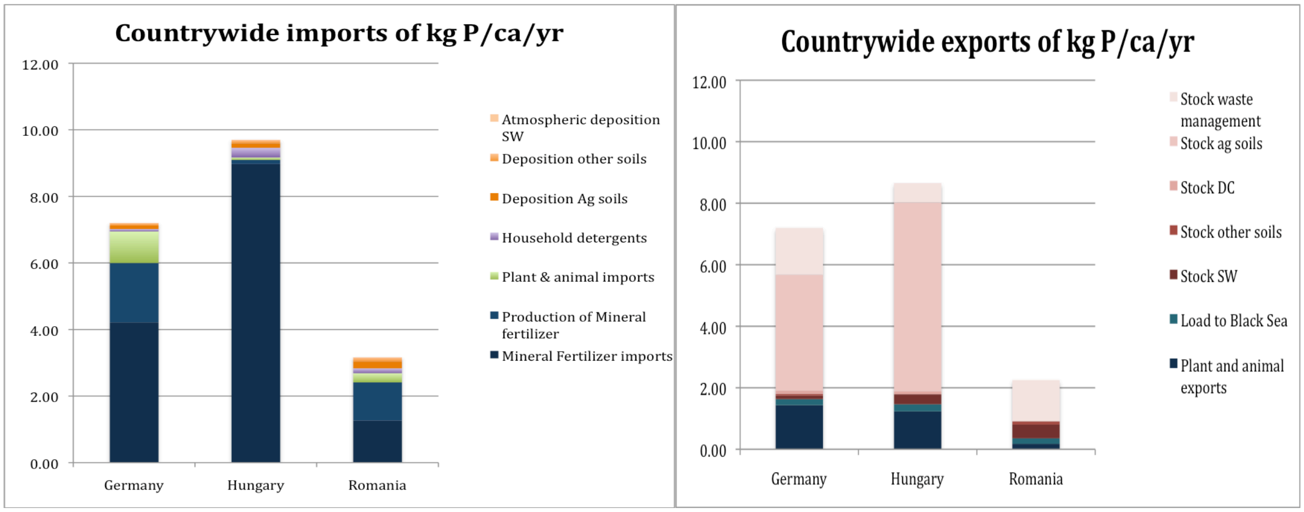


Figure 22: **Countrywide imports and exports of phosphorus flows for Germany, Hungary and Romania from 2000-2005.**

For countrywide phosphorus balances, as for nitrogen Germany imports more plant and animal products compared to it's two downstream neighbours and exports only slightly more than Hungary. Another obvious observation is Hungary's huge consumption of phosphorus fertilizer per capita and year.

As the plant and animal imports flow is the most noticeable difference between Germany and the other countries, this will be broken down further. The following table compares plant and animal exports minus imports for each country:

Table 9: **Exports minus imports of plant and animal products for Germany, Hungary and Romania:**

	Nitrogen		Phosphorus	
	Kg/ca/yr	**Kg/ha/yr**	**Kg/ca/yr**	**Kg/ha/yr**
Germany	2.3	6.6	0.2	0.7
Hungary	6.6	11.5	1.2	2
Romania	-0.3	-0.4	-0.1	-0.15

Clearly Romania imports more than it exports plant and animal products. Interestingly, Hungary exports much more in relation to imports compared to Germany. This will be further analysed in detail in the discussion chapter. As it was observed earlier in the results section and in the background of this thesis that one of Germany's main exports is livestock, Table 10 will break down exports and imports into plant exports versus animal exports per capita:

Table 10: **Exports minus imports of plants and animals in Kg per capita and year for Germany, Hungary and Romania.**

	Nitrogen (Kg/ca/yr)		Phosphorus (Kg/ca/yr)	
	Plants	**Animals**	**Plants**	**Animals**
Germany	1.3	0.3	0.3	0.02
Hungary	5.63	.86	1.07	0.1
Romania	0.2	-0.42	-0.01	-0.1

Given the results above Hungary still exports more plants and animals than Germany per capita. This will be discussed further in the discussion chapter.

Conclusion: Results

For nitrogen, the flow percolation from agricultural soils was the dominant flow for Germany. In the case of Hungary and Romania the combined flow coming from wastewater contributed more nitrogen than agricultural percolation, however the latter still played a significant part in the surface water emissions, and as this study will focus only on diffuse, or nonpoint flows of nutrients, this is the flow that will be discussed further.

For phosphorus, wastewater was the main contributor for obvious reasons. This flow varied between countries, however. For Germany agricultural erosion contributed the most phosphorus to surface waters. This is most likely related to the higher development of wastewater treatment in Germany versus Hungary and Romania. Again, as diffuse flows are being focussed on in this thesis, the erosion flow will be focussed on as the highest diffuse P flow to surface waters.

The loss of N through the percolation flow to surface waters from agricultural soils was higher when the application of mineral fertilizer and manure was higher, as in Germany’s case. Agricultural groundwater was not a big factor in nutrient losses to surface waters in Romania in comparison to Germany and Hungary. This could be attributed to a lack of nutrients in Romania.

Figure 19 & Figure 20 clearly show how much more meat and animal products Germany produces as a whole. This is the one variable that is noticeably bigger in Germany compared to Hungary and Romania. A larger amount of manure is correspondingly applied in Germany and it can be assumed is contributing to groundwater losses in Figure 15 & Figure 17. As the nutrients required for the production of meat and animal products is much higher compared to that of plant products, this explains the very high feedstuff N value for Germany (Figure 16). It is also observed that Germany imports more mineral fertilizer and plant and animal products. As these higher imports results in higher nutrient losses to surface waters, this will be further considered as an indicator.

LITERATURE REVIEW

The discussion section of this thesis will follow, however a literature review looking at previous indicator considerations will preview this chapter in order to put the consideration of indicators in this study into perspective. Before explaining and justifying the most significant flows described above, which will be followed by the suggestion and definition of an indicator flow or flows that could be universally applied to all EU countries, the political, economical and ecological consequences of such an indicator will be reviewed from the literature. Finally, suggestions will be made as to possible policy implications this could have for the EU as far as the Water Framework Directive and the Nitrates Directive are concerned.

Important flows

Nitrogen

The most significant flow of nitrogen to surface waters and therefore with the most potential to cause eutrophication in this study was the percolation to groundwater flow coming from agricultural soils. Germany contributed the most to this flow at 7 kg nitrogen per capita per year. Romania followed with 2.79 kg of nitrogen per ca and yr. Hungary was the lowest contributor at 1.6 kg of N/(ca.yr). A history of high retention rates in Hungary can account for this result (Figure 23). It is clear that nutrient emissions were higher in countries with higher population densities and livestock densities per agricultural area. GDP per capita is 10,700 USD for Romania, 19,400 USD for Hungary and 34,000 USD for Germany. GDP values were taken from the CIA database for 2006, and take purchasing parity into account. Csathó et al (2009) observed a positive correlation when plotting per capita GDP and the application of organic and mineral fertilizer for all countries in the world. Csathó et al (2009) also showed a higher livestock density correlation with higher population density.

The results from this study have shown a much larger meat and animal products flow in Germany compared to Hungary and Romania. Given the higher amount of nutrients needed for animal products, Germany has the largest nutrients attributed to feedstuff, manure and also imports both of Nitrogen fertilizer and plant and animal products. It is not known from the data in this study how much of these imports go to feedstuffs, an example of where future studies need to focus. This observation will be taken into consideration in the final indicator discussion.

Phosphorus:

The predominant input flow here was also attributed mostly to organic and mineral fertilizer. Feedstuffs and plant products just edged out erosion from agricultural soils for Germany, whereas wastewater was the main flow for Hungary. Feedstuffs and plant products almost exclusively dominated Romania's phosphorus output. The history of phosphorus fertilizers in western versus eastern European countries can help explain this. The application of phosphorus fertilizer started a few decades later in Eastern Europe compared to the west. This accounts for the lower P balances in these countries in the 1960's. In the 1980's a trend of intensive application of these fertilizers developed, resulting in huge surpluses. Since the 1990's however, the economic breakdown of post communist member states has resulted in a steep decline in the intensity of use of such fertilisers. Due to the storage of the surplus application of the 1980's, phosphorus carryover effects have allowed for such small outflows as those observed in Romania in this study.

Results in comparison to other literature

There are no results pertaining directly to the time frame, regions and specific scope of this study, ie: diffuse sources from agriculture. However Schreiber et al, 2003 published results for the whole of the Danube Basin from 1998-2000. The study didn't concentrate specifically on agriculture, however there were results involving agricultural diffuse sources. For all three countries these results were a bit lower than the present study, at 2606 t P /yr for Germany, 2036 t P/yr for Hungary and 8003 t P/yr for Romania.

The 2008 OECD study on Agricultural activities in OECD countries from 2000-2006 included nitrogen balances for Germany and Hungary. It must be taken onto account that the Germany values included the whole of Germany rather than the Danube River basin portion focussed on in this study. Keeping this in mind, the N efficiency was reported at 50%, and N balance was 133.3 kg/Ha. For Hungary, the nitrogen efficiency was reported at 62 % and the nitrogen balance was 37.1 kg per ha. At closer inspection of the methodology used for the OECD study, arable land and permanent cropland were treated differently as far as fertilizer and use was concerned. It was admitted in the introduction that the comparability of data was, 'particularly unsatisfactory' when the permanent grassland data were concerned, as the land use definitions employed by each country varied considerably. This further underlines how critical methodology is when it comes to developing a universal monitoring and River Basin Management system in the Danube River Basin.

Further discussion: History & geology

Having established the flow of agricultural percolation to groundwater as a significantly important diffuse contribution to nutrient loads in the Danube River Corridor and into the Black Sea, it is important to compare trends over history and natural hydrology in the different regions concerned.

As far as historical emissions are concerned, observations can be made on the historical data concerning fertilizer application and agricultural habits. These data can be compared to the resulting nutrient loads into the Black Sea. As has been already discussed at length in the introduction, emissions to the Black Sea were last at ‘acceptable’ levels in the 1960’s. Between 1960 and 1988, the application of fertilizers increased 4 to 5 fold in the whole Danube river catchment area in western and eastern countries alike. The breakdown of the communist economies led to a drop there to around mid 1960’s levels, whereas in Western Europe it remained more or less the same. An all time low of fertilizer applications hit in the mid 1990’s, due to political pressure resulting from intense eutrophication of the coastal Black Sea area. Levels have since increased however and there remains a concern that levels will reach dangerous levels again with the intensification of agriculture in the CEE countries.

The historical measurements of emissions to the surface waters in the Danube Basin can be observed broken down by sources in figure 5 and directly reflect the changes in fertilizer applications over the years. Having established the source of this flow, and the main pathway it takes to the Danube corridor, further observations from the DANUBS study can clarify the behaviour of nitrogen during it’s journey to the water body in question. This varies considerably from region to region, and so this understanding is critical regarding the decision of final mitigation measures, which will be discussed in the next chapter.

Denitrification

The loss of nitrogen, mostly through denitrification is taken into account by the MONERIS model, and varies considerably from region to region. The retention of nutrients in soils is completely dependent on the nitrogen surplus on agricultural land, the hydrological characteristics of the catchment and the amount of leached water within the subcatchments. The retention in the soils and groundwater varies from between 62% (Sava) and 99% (Delta Liman) (DANUBS study, 2005). If agricultural land is drained artificially this value is obviously reduced. Figure 22 illustrates the variation in the percentage of nitrogen retention along the Danube river basin:

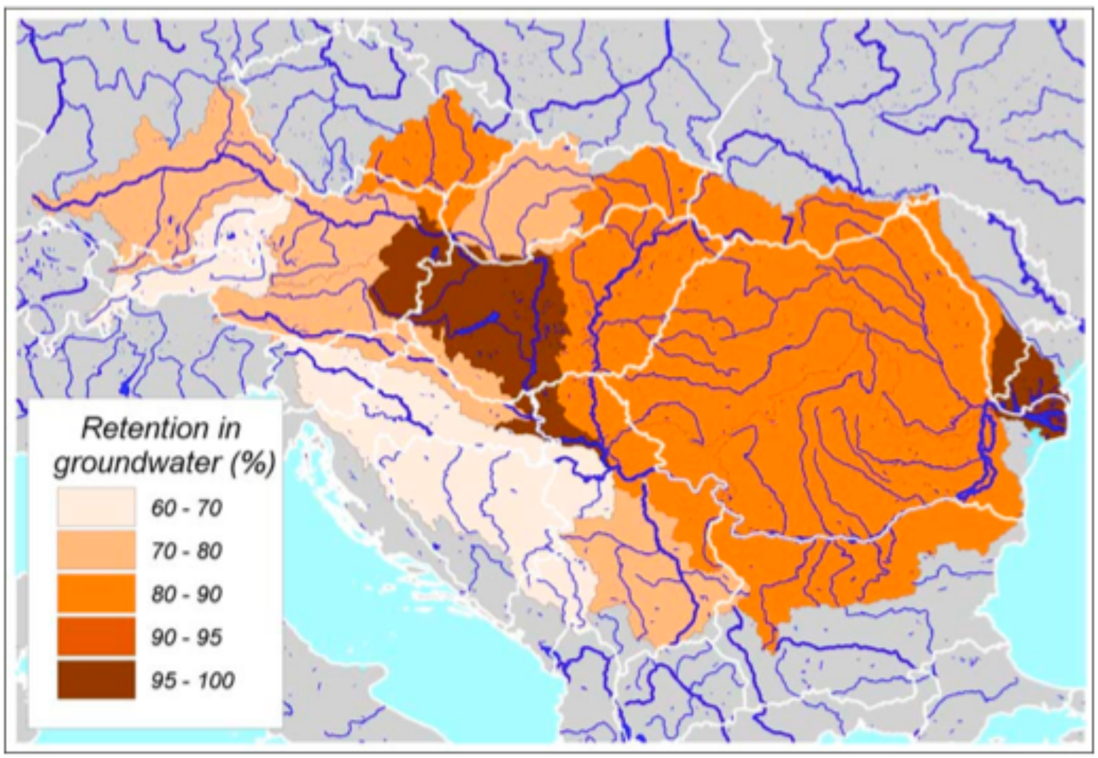


Figure 23: **Distribution on a sub basin scale of the retention of nitrogen in groundwater. (DANUBS, 2005).**

One immediate observation regarding nutrient retention is for Hungary. The high retention in this region is reflected well in the low percentage of excess nutrients that make it form the agricultural soils process to the surface waters process in this study. This is a perfect example of variation in hydrology and geology between regions, which must be kept in mind for future policy considerations. Denitrification, the key process contributing to retention is influenced by geology, precipitation, groundwater recharge rates and residence time in groundwater.

As far as hydrological aspects of denitrification go, groundwater recharge rates determine the input of nitrogen and oxygen into groundwater. Higher residence time in groundwater also influences this process – studies have shown that in countries with high precipitation, and therefore low groundwater residence time and high recharge rates, denitrification is much lower than regions with low precipitation (Zessner et al., 2004). For future management plans this means particular attention must be paid to wetter regions.

To conclude regarding groundwater and the behaviour of nitrogen loads, future management measures that are taken must not only take hydrology of each region into account, but also the time of year they are applied given the high correlation of the denitrification process and precipitation.

Soils & Phosphorus

As primary productivity causing eutrophication of the Danube River Basin is phosphorus limited, Csathó et al (2007) compiled a literature review to evaluate, based on some selected pressure and state indicators, recent changes in agricultural practices and the impact of phosphorus from these practices on the trophic status of the surface waters in Eastern and Central Europe. Several take home points in this paper stressed the importance of factors that must be taken into account in future studies on considering phosphorus as an indicator. Soil phosphorus status by country, water erosion and phosphorus loads to surface waters were investigated in detail given the available data, which, it was concluded, is insufficient to date.

Phosphorus balances in all countries has tended to be directly linked to the farm sizes in each country, which vary sharply. More specifically, the livestock density in CEE countries were found to be only one tenth of that found in western European countries, explaining the large variation between Romania and Germany.

Soil phosphorus status is also important when evaluating phosphorus balances. Csathó et al (2007) estimated the soil P status in all CEE countries. Over time, P balances have varied sharply with the west for economic reasons. In the 1960's, soil P levels were poor in 40%-80% of the area. Once more intensive fertilizer application was introduced the 1980's, the proportion of low status diminished to15%-60%. Starting in the 1990's the restriction of P application due to the effects on the environment has caused an increase in poor phosphorus supply at 25%-70%. The large variations are attributed to differences in social, economic, ecological and climate status in each country, and sometimes within certain countries.

It was found that water erosion affected each country differently, depending directly on the lowland area in each country. Overall eroded area was the smallest in countries with extensive lowlands with the exception of Slovakia due to different land use patterns. Csathó et al (2007) concluded that the main reason for agricultural diffuse phosphorus loads to surface waters is erosion. This went on to explain that as Romania occupied that largest area at 37% of surface waters in the Danube Basin, it was responsible for the largest load of TP at 58%, 52% coming from agriculture. If only diffuse phosphorus loads are taken into account, it was estimated that agriculture accounts for 9-40% of the TP load in the whole of the Danube River basin, 44% of which comes from diffuse sources.

The P index

Finally this study considered the P loss risk index developed in the USA as a universal way of assessing the environmental effects of agriculture (Sharpley et al, 2003). To quickly sum up this index, it was calculated for Europe through first of all developing an erosion index, weighting factors 1,3 and 5 for slight, moderate and severe erosion respectively. This was multiplied by the corresponding area percentages for each country. The annual phosphorus balances were considered as an indicator of the long term P surplus in agricultural soils, and this was multiplied with the erosion index. The final result was plotted against total P content in rivers, and in the end a sufficient relationship could not be found. This was most likely due to diverse data calculated using different methods.

It was concluded that the wide variation in data acquisition, and methodology make this final comprehensive evaluation difficult for such an international River Basin such as the Danube River Basin. As a similar methodology for both N and P will be considered for this study, close attention will be paid to this complication and further suggestions will be made for further studies.

Methodology of MFA: complications and future considerations

Before this analysis moves forward, it must be noted that the OECD method for nutrient balance was followed for all three countries however due to calculation problems, several adjustments had to be made. Again, most problems stemmed from the Romanian MFA. In order for a consistent evaluation of nutrient flows that could be analysed as a universal indicator for agricultural activities in the EU, the same nitrogen and phosphorus coefficients had to be applied. Upon further observation of the animal breeding process of the Romanian system, these coefficients resulted in a significant excess amount of nutrients leaving livestock as had entered the animal breeding process. In order to maintain the law of conservation of mass/matter, the output flows from this process (manure, NH_3 emissions) had to be adjusted to equal the input values of feedstuffs. It can be realistically assumed that the nitrogen content of manure from Romanian animals is less than that of German or Hungarian animals given that their feedstuffs are of lower nitrogen and phosphorus content. It is also possible that Romanian livestock have less production cycles a year compared to western European countries, which is a factor taken into consideration for the OECD N and P coefficients for manure (OECD, 2007).

OECD material flow accounting methodology

For indicator analysis, the OECD (2000) makes several suggestions as to how to proceed in order to construct a useful indicator for policy makers. Firstly, it is recommended that the cause of the said indicator is well identified and defined. In this case, eutrophication is the problem that future policies want to contain. Secondly, attention should be made to the present management of the substances in question and the costs and benefits of future management practices. Third of all, the indicator should contribute to the development of an early recognition system for future problems, in this case eutrophication. Finally, the chosen indicator should help with the implementation of future policy measures and mechanisms (OECD, 2000).

For long-term sustainability and environmental policy at EU and Member States level, resource use and resource efficiency has come up as a major issue. Future objectives therefore include increasing the resource efficiency within the economic system, which would result in the reduction of natural resources used, allowing for a reduction in negative impacts on the environment. Therefore the 'total quantity used' and the 'efficiency of use' are policy relevant themes to bring into indicator interpretation. It is important that concerning nutrients, if increased efficiency of use should lead to a decrease in economic growth it will ultimately fail as a policy mechanism.

Finally, as nutrient indicators are always connected to other indicators, they should be analysed in their context also. This could include but is not limited to water quantity and use, waste management and production, climate change, and land use. In the case of this study, all these indicators have an effect on the flow of nutrients and where they eventually end up, and so will be considered during further analysis.

Eutrophication: definition.

Before any further discussion or analysis can be made on the speculation of possible indicators, the specific role that both nitrogen and phosphorus play in the process of eutrophication should be made clear, as this is the pollution problem most affecting the Danube river basin and the coastal Black Sea. This definition must be kept in mind whilst considering the indicator flows identified in this study.

Eutrophication is defined as the triggering of primary productivity in a water body due to the introduction of certain indicators. The link between anthropogenic sources of nutrients and the emergence of eutrophication is well accepted (Ærtebjerg et al., 2001; Smith, 2006). Not only nutrient loads can be considered as causes, however. More recently, climate effects such as temperature increases and overfishing have also been known to alter ecosystems enough to cause eutrophication (Daskalov, 2002). The understanding of anthropogenic causes of eutrophication has been studied intensively over the years, from which non-linear responses to indicators has been found (Beaugrand, 2004). As a result of the Water Framework Directive, as well as the Marine Strategy Directive, monitoring programs are becoming mandatory for EU member states in order to attempt at predicting such a phenomenon.

In the case of the Black Sea, as was explained earlier eutrophication was a problem in the 1980's due to increased use of fertilizers, detergents, fossil fuel consumption and lack of sewage treatment but has since abated due to the economic collapse of the post communist Danube river basin countries. The present concern is that nutrient loads will rise with economic recovery. At present, the response of certain ecosystem indicators to increased nutrients has been studied, but the development of actual quantitative links between nutrient pressures and ecosystem changes needs further study. This thesis will help address part of this problem by attempting to identify which flow of diffuse sources of nutrients from agriculture contributes the most to this nutrient pressure.

The first step to monitoring eutrophication risk is to develop consistent, solid data sets in river basins where this has or could be a potential problem. For the Danube river basin, this also needs to be the case. Policies addressing this problem include the EU Water Framework Directive, which is still at an early stage of implementation. There are also new plans or pressures to expand agriculture for biofuel crops as well as for food and fodder. These plans vary greatly across specific regions, and the highly variable behaviour of River basin emissions due to different climates, soil retention and hydromorphology also vary greatly between regions. It is for these reasons that future policies must cater specifically to each River Basin in question (McQuatters-Gollop, A. et al., 2009). The challenge of this study is to identify a common indicator flow in such a large River basin, and suggest how it could be fairly applied to all EU countries.

Nutrient management: cost benefit across the Danube river basin

Given the results obtained, consideration of several mitigation measures will be made that have been put forward by the literature. These will be applied to the current study, and given the future scenarios envisioned by previous studies, they would be evaluated as to their applicability for future policy considerations using the indicators generated from this study.

Cost-efficiency analysis: Optimisation for each country separately

As each country, given their opportunity to decide would choose the measures that would incur the least cost to them, a problem is immediately evident. No one measure can be universally applied to all European countries, or even the three countries focussed on in this study. It is for this reason that Fröschl et al (2008) suggests the ranking of measures according to their net cost-effect ratios, based on either nitrogen soil surface surplus, or nitrogen load flowing into the black sea. Either ratio results in the same ranking of countries, and obviously the lowest ratio is to be chosen for each country.

The use of a universally applicable indicator facilitates this decision. Obviously first a decision has to be made regarding a specific quantitative objective, which will be further discussed in the policy chapter following this one. If consistent data sets were generated allowing for solid nutrient balances for all European countries, the resulting soil surface surpluses could be plotted against the established costs for possible measures, which could then be applied at a minimal cost or even profit to each country (figure 23). In the case of this study, the surplus of nutrients through agricultural percolation (will be defined shortly) to groundwater would apply well as a potential indicator for these cost ratios. Cost benefit analyses are further analysed by Wade (2009) who argues that it has the potential to consider mitigation proposals in terms of societies total environmental and economic impact in monetary terms. A formula was designed that in theory is applicable to any water system.

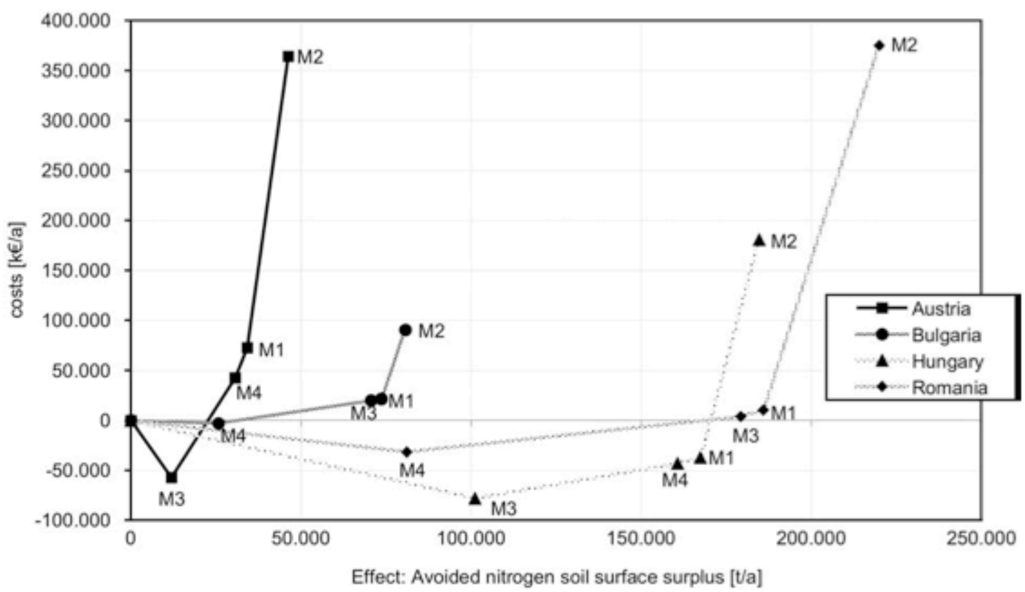


Figure 24: **Ranking of measures to avoid nitrogen soil surface surplus in Austria, Bulgaria, Hungary and Romania in relation to their cost-effect ratios. (Fröschl et al., 2008).**

The effects of such measures on the nutrient load into the Black Sea should be evaluated cautiously however. Each country in the Danube River Basin has different retention rates of nutrients both in tributary rivers and in soils. They also vary considerably in climate conditions. Hungary for example retains 61.4% of its emitted nitrogen in local rivers and streams, allowing for only 39% to flow to the Black Sea. Austria on the other extreme retains only 31% of nitrogen, the rest of which is transported to the Black Sea. It is due to these discrepancies that nutrient soil surplus would be a less biased indicator upon which to base a cost effect ratio. It is more solidly connected to emission sources, yet closely enough connected to the reception site that the benefits of reduction could be accurately calculated.

Mechanisms controlling nitrate pollution

Controlling nitrate pollution was analysed for a smaller catchment in the UK, and how various policy mechanisms affect the overall final load to the river in question. A model measuring nutrient pathways similar to the MONERIS model was used, and the assumption from a previous literature survey was that input taxation of fertilizers is superior to emissions taxation. An economic model was then formulated measuring how various policy decisions both affect the farmland and the final nutrient emissions to surface waters. Policies similar to those discussed earlier were considered, including stocking rate limits, timing of fertilizer applications and soil management such as the restricted use of ploughing. Contrary to Fröschl et al (2008), the results indicated that either a combined policy including a small percentage of each measure and an input taxation were the most effective policy measures as far as reducing nitrate emissions. The only issue with this final conclusion was that the effects on land use and productivity were huge. Reductions in productivity included 2% for oilseed rape to 12% less for linseed.

So as far as the economic implications of nutrient control are concerned, lessons can be learned from previous studies. The agricultural percolation to groundwater flow identified in this study, that directly relates to the surplus of nutrients from agricultural soils can be applied as an indicator for cost benefit analyses of various policy measures. Measures will vary across countries as the hydrological dynamics vary greatly as do the market prices of fertilizers and best available technology. As far as taxation measures goes, this could be used as an incentive to apply the most cost effective 'best available practice'. Perhaps only the use of excess fertilizer could be taxed, the proceeds of which could go to helping Eastern European countries fund best available technology. Whatever method is applied though, more studies should focus on the effects of these measures on agricultural productivity. It is possible that due to the small size of the river catchment studied in the O'Shea & Wade study, the magnitude of the efforts needed to reduce the nutrient load were much higher over a smaller surface area, leading to a much reduced productivity of agricultural crops. The Danube River Basin benefits in this respect, as due to it's large surface area, more nitrogen is retained in it's soils and tributaries, leading to an eventual smaller load to the Black Sea. This should not allow for excess nutrient application however and consistent detection methods should still be applied to DRC soils, fertilizers and waters in order to keep an accurate running nutrient balance.

Politics

Water Framework Directive

The Water Framework directive entered into force on the 22 of December 2000 and is aimed at providing a comprehensive approach to improving water quality. This includes legislation such as the Nitrates Directive, which is designed to reduce the pollution of surface and ground waters due to nitrate emissions coming from agricultural activities. The following section will discuss the results needed for 2015, and the implications of the use of such an agricultural indicators in achieving these goals.

As was described in the introduction chapter of this study, a River Basin Management Plan has been established to coordinate mitigation measures across the Danube River basin. Given the observations made in this and previous studies, the importance of working at different geographic scales, in particular via sub-basins of the overall Danube basin is vital.

For future policy measures, as described by the OECD, it would facilitate the decision of what mitigation measures to take and where if there existed an early recognition system of future nutrient emissions and loads into the DRC. Given the agricultural percolation to groundwater flow that was found to contribute the most to these emissions, the following recommendations should be made.

First of all, the nutrient measurement and balance methodology must be consistent from country to country. In particular, as was found for Romania in this study, the OECD method for calculating nutrient balances is currently biased. Attention should be paid to the nutrient content of feedstuffs and this should relate directly to the nitrogen and phosphorus content of manure, rather then a universal manure coefficient, which does not reflect the N/P application to agricultural soils accurately. Furthermore, the data used for each country balance must be transparent, consistent and accurate. The data currently available was only estimated by the FAO especially for Romania, which led to the need to calculate many flows from other known data. This increases the uncertainty of the whole system.

Next, as the storage capacity of nutrients in the DRC catchment is orders of magnitude higher then the yearly turnover, consistent data on the current nutrient content of soils must be maintained along with the geologic, morphology and climate conditions of each region. For the case of groundwater, which was described earlier, overall drier countries tend to retain more nitrogen than those with higher precipitation. A designated surplus of nitrogen should be decided upon keeping this variability in mind. In the case of phosphorus, a large contributor to P surplus related to the history of P fertilizer application in the western versus post communist European countries. The West is able to sustain crops with virtually no P fertilizer due to carryover effects whereas eastern European countries are suffering with production due to negative phosphorus balances.

Overall, the significant flow of nitrogen and phosphorus in groundwater from agriculture contributes to ~40% to 80% of total agricultural emissions, which are reduced by 40% to

50% by the time they reach the Danube River Corridor. As diffuse agricultural sources contribute 32% and 46% (DANUBS, 2005) to total emissions to the DRC, focus on this flow would significantly help to curb diffuse sources of nutrients into the Black Sea. A curbing of surplus nutrients to agriculture would also reduce NH_3 emissions into the air, a flow which travels to other sometimes remotes areas and will deposit onto surface waters, further exacerbating the nutrient load problem.

DISCUSSION

Definition and identification of a potential indicator

This study has so far presented many findings, which have been broken down process by process. In this final chapter, the pertinent results will be further analysed by country and the results will be measured up to potential indicators. These indicators can be presented as follows:

- Area specific or inhabitant specific nutrient emissions to surface waters
- Nutrient concentrations in national ground or surface waters
- Imports, exports of agricultural products per capita
- Amount of fertilizer per area used on crops
- Agricultural productivity per area or per inhabitant
- Surplus of nutrients in agriculture per area
- Surplus of nutrients in agriculture per inhabitant

Finally, one or several of these indicators will be singled out and it's applicability as a benchmark of nutrient management in respect to environmental protection in general and protection of the Western Black Sea coastal areas and the Danube River Corridor specifically will be discussed.

A discussion of the results should prelude the defence of any one or several indicators. It was established in the introduction of this thesis that the predominant diffuse sources of nitrogen are coming from the base flow or more specifically the percolation from groundwater flow. Most diffuse phosphorus emissions are documented to be coming from erosion (Brunner et al 1997). This was proved most clearly in Germany's case, where these two flows did indeed predominate over the others. Wastewater overtook percolation and erosion in Romania most likely due to its less developed wastewater management. In Hungary's case, total emissions to surface waters were altogether lower, leaving wastewater also to predominate. This can be attributed to its high retention of nitrogen (Figure 23).

N to Surface Waters

Overall emissions to surface water followed the same order per total hectare and year values and per capita and yr values. Nitrogen emissions were highest for Germany, which can be attributed to high livestock values and will be broken down next. This was followed by Romania, then Hungary. As described above, retention of nitrogen in Hungary is recorded as very high, explaining it's low total emissions to surface waters.

P to Surface Waters

This varied per total area hectare and year and per capita and year. Per capita and yr, Hungary emits the most phosphorus, most likely due to less efficient WWTP nutrient removal and soil erosion problems (OECD, 2008) (Table 4). This was followed by Romania then Germany. As Romania is documented to have increased P loads due to housed livestock (Csathó et al, 2007), this could explain Romania's values. Per ha and yr, Germany emits the most phosphorus, followed by Hungary then Romania. Again as above, Germany has a much higher livestock production per hectare compared to Hungary and Romania. This will be looked at in detail in this chapter.

N to and from Agriculture:

The process agriculture revealed more specifically how much nitrogen is being applied to agricultural soils, helping to understand the corresponding losses from each country to its surface waters. The amount applied per hectare and year is clearly higher for Germany, then Hungary and the least in Romania. Given the higher population and livestock density in Germany, per capita values can perhaps more fairly describe nutrient application. Here Germany and Hungary apply an equal amount of mineral fertilizer and Romania applied comparatively little.

Germany looses twice as much nitrogen overall per agricultural hectare and year compared to Hungary (Figure 19). Per capita, relatively equal amounts of nitrogen are lost to the air from Germany and Hungary. Losses to water however are much higher in Germany both per ha and yr and per ca and yr. Looking at the difference in productivity between these two countries, as has been repeatedly observed; the overall production of animal products, including milk is much higher in Germany. It should be noted at this point that there is a large difference between meat and animal products produced per capita and yr in Germany (7 kg N/(ca.yr)) and the amount consumed per capita (3.5 kg N/(ca.yr)). The same gap can be observed for Phosphorus and has to be attributed to a lack of data regarding meat consumption in Germany.

P to and from agriculture

The same can be argued for phosphorus per ha and per ca in Germany compared to Hungary and Romania. The only difference lies in the huge application of phosphorus fertilizer per capita onto Hungary's soils. It can be argued that this is due to runoff from it's abundant application of phosphorus in the 80's, and it's large export of animal products (Table 10) which requires a much higher nutrient input compared to plant products.

Whole country balance

The only losses seen here (Figure 21) are denitrification for nitrogen and stocks for phosphorus. Germany and Hungary loose more or less the same in this respect. Romania both produces and looses much less.

Figure 19 illustrates the take home point when justifying nutrient applications to soils and losses to soils. Germany produces much more livestock, or meat and animal products compared to Hungary and Romania. Even though Hungary exports more per capita compared to Germany, Germany still produces more livestock and it's products (ie: milk) as a whole. Given the much higher nutrient requirement for meat products, especially dairy cows this explains Germany's much higher mineral fertilizer application (imported plus produced) to its soils. Relating back to the hypothesis of this thesis, higher livestock values translate into a higher manure application to soils than is needed. The resulting excess in nutrients reflects the high losses from Germany illustrated in this study.

Romania

The results for Romania illustrate its lack of nutrients. So much land and therefore fertilisers are being attributed to livestock according to this study (Figure 16) that it must actually import more plant and animal products than it exports (Table 9 & Table 10).

Discussion of potential indicators

Keeping these results in mind, several possible indicators will be discussed.

Area specific or inhabitant specific nutrient emissions to surface waters

This is a potential solution to the nutrient emission problem. Every country could emit the same amount of nutrients per capita or per hectare. This would not treat all countries in a fair way, however. Romania and Hungary have per capita densities per agricultural hectare of 1.7 and 1.5. This can compare to Germany with 3 inhabitants per agricultural hectare. In theory this would mean that Germany could only emit just as many nutrients per hectare compared to Hungary or Romania and would suffer due to its higher population. In reality Germany is emitting 12.5 kg N/(ca.yr) to Surface waters where Hungary and Romania are emitting 6 kg N/(ca.yr) and 4 kg/(ca.yr) respectively. With the reduction per area scenario Germany would end up with the same productivity in relation to many of it's less dense neighbours, and would end up not being able to sufficiently feed it's population or export any products.

On the other hand a reduction per capita would solve the population density problem, however less dense countries would then suffer, as they would not be able to increase the productivity of their land for exports of plant and animal products. Inevitably countries such as Romania will want to expand and develop. With a reduction of their already low emissions this will prove to be an impossible task to accomplish.

Nutrient concentrations in national ground or surface waters

Another indicator that could be considered is the concentration in either ground or surface waters. A 'ceiling' nutrient concentration could be set, and all surface water concentrations could be put at the same level for every country. The problem with this is that at a ceiling level the issue of differing geology and climate between countries is still not accounted for. Countries with a geology such as Hungary and with higher inland recharge rates of water will fare better and be able to emit more nutrients than countries with lower inland recharge water rates.

Before moving on any further, it should be kept in mind that surplus nitrogen applied to agricultural soils is always lost to the environment, mostly through denitrification as was described in the methodology chapter of this study, and is well illustrated in the results (Figure 21 & Figure 22). Surplus phosphorus on the other hand has a much higher retention time in soils, and is eventually lost at a slower rate to nitrogen almost entirely through erosion (Brunner et al, 1997). This is illustrated well in the agricultural soils results in the results chapter. The previous two indicators already discussed had problems primarily with the differing denitrification rate, geology and climate amongst countries.

Surplus nutrients in agriculture

Upon analysis of the results of this study, some interesting observations can be made regarding a surplus application of nutrients on agricultural soils in these three countries. A major problem with emissions to surface waters and to the Black Sea is the variable denitrification and retention rates amongst countries, it makes sense to take a step back in the emission process and take a look at actual nutrient application before any significant losses through denitrification, ammonia losses and erosion can take place.

First of all if a 'surplus' application of nutrients is to be considered as an indicator, this term needs to be properly defined. The purpose of applying nitrogen and phosphorus is to grow or breed plants and feed animals for the eventual generation of agricultural products for consumption and export. It would therefore make sense to measure the nutrient content of inputs and outputs of products into and out of agriculture as a whole and then compare these values (Table 6). The difference between these two values can be considered 'surplus' nutrient application. The results of this study illustrate these surpluses well in Figure 19, Figure 20 and Table 5 & Table 6. For agriculture as a whole, where internal flows such as manure and agricultural feedstuffs were not taken into account, a few observations were apparent.

Surplus in agriculture per hectare

For per hectare/yr nitrogen values, Germany led with surplus nitrogen of 70 kg per hectare and year followed by Hungary at 37 kg per hectare and yr and finally Romania at 14.5 kg per hectare and yr. As Hungary and Romania both have roughly the same population density at 1.5 and 1.7 inhabitants per agricultural hectare, it can be assumed that Romania's low GDP per capita can account for it's significantly lower surplus value in comparison with Hungary. This could indicate a lack of nutrients.

As far as per hectare phosphorus values are concerned, the numbers are a little less clear, most likely due to the retention of phosphorus in soils, compared to nitrogen, which is mostly lost to the environment. Both Germany and Hungary are recorded to have a significantly higher phosphorus surplus compared to Romania, which is negative. In the case of Germany this can be attributed to soil erosion and runoff as can be seen in Figure 10. The phosphorus fertilizer was especially high in Hungary's case (Figure 17). For Romania the economic breakdown that resulted in low phosphorus fertilizer applications can account for Romania's negative phosphorus balance.

So from this analysis it can be concluded that using surplus nutrients per agricultural area is a good indicator for nitrogen and any potential mitigation measures would be kinder to countries with lower population densities per agricultural area. This will be investigated further.

Surplus in agriculture per capita

Here the surplus values were a little more equal across countries, with 25 kg N/ca for Germany, 22 kg N/ca for Hungary and 4 kg N/ca for Romania. Again, Romania's low GDP per capita can explain its low surplus, whereas Germany and Hungary's values reflect their population density and GDP per capita.

For phosphorus agricultural surplus values per capita, again Hungary was somewhat of an outlier with 6 kg P/ca surplus accompanied with stock of 6 kg P/ca compared to Germany with 4 kg P/ca ± stock of 1 kg P/ca and Romania with -.03 kg P/ca. It should be noted that Romania's phosphorus balance is negative. Romania's negative phosphorus values accompanied with a relatively low loss of phosphorus to erosion can explain it's lower productivity, and lack of nutrients compared to Hungary and Germany.

The next section will be devoted to singling out where the majority of agricultural nutrient surpluses are coming from by country, and how this relates to losses of nutrients to surface waters.

Amount of Fertilizer (manure & mineral fertilizer) per area used on crops & crop productivity

Having established that surplus nutrients per capita could be singled out as a potential indicator for future nutrient management, it is logical to look at the amount of mineral fertilizer and manure applied per capita and yr and per hectare and yr by country given that this is where the majority of surplus nutrients are coming from (see Figure 15 & Figure 17). Given the results of nitrogen per hectare for example, 85% of Germany's import nitrogen to agricultural soils came from mineral fertilizer. 82% of the same came from Hungary and 80% came from Romania. Per area this translates into 105 kg nitrogen per ha from Germany, 59 kg N per ha from Hungary and 18 kg N per ha from Romania. The production of plants versus meat and animal products immediately explains these results. Figure 19 clearly illustrates how much more livestock is produced by Germany compared to Hungary and Romania. Figure 20 illustrates the same result for phosphorus regarding the difference in animal products produced.

At this point it has been established that the amount livestock produced by a country has an enormous effect on the agricultural surplus of nutrients coming from soils. At this stage it would be important to discuss a more specific definition of this surplus keeping this in mind.

Every country has the right to produce enough meat for it's population and every country should be allowed to export meat and animal, as well as plant products. Specific numbers of livestock necessary for each country are beyond the scope of this study, however it is assumed that there exists a marginal amount of fertilizer and/or feedstuffs needed to adequately produce livestock. In this respect it would interesting to next look at the amount of fertilizer and feedstuff imports between countries and compare this to their production of meat and animal products.

Imports, exports of agricultural products per inhabitant

Results from the industry process can perhaps further clarify the source responsible for excess agricultural nutrient applications.

Indeed, looking at Nitrogen imports of mineral fertilizer and plant and animal products, this same logic is observed. Germany imports 23 kg of nitrogen via mineral fertilizer per capita and year, whereas Hungary imports 17 kg N/(ca.yr) and Romania imports 1 kg/(ca.yr). Phosphorus doesn't quite follow, as Hungary imports significantly more through mineral fertilizer at 9 kg P/(ca.yr) compared to Germany at 4 kg P/(ca.yr). As explained earlier this can most likely be attributed to the fact that Hungary's soils are stocking less phosphorus compared to Germany given that it has had less opportunity to apply it given it's economic past.

Germany imports 9 kg N in plant and animal products per ca but exports 11 kg N per ca. Similarly Hungary imports 0.5 kg N per ca but exports a much larger 7 kg N per ca. Romania exports and imports about the same amount of nitrogen at about 1.5 kg per ca. For phosphorus Germany and Hungary export only slightly more than they import by about 1 kg P per ca. Romania exports slightly less than it imports. This should be taken into account when defining surplus nutrients applications to agricultural soils as a potential indicator. An increase in imports of plant products, some of which goes to feedstuffs and an increase in mineral fertilizer imports clearly contributes to surplus nutrient applications and therefore losses from agricultural soils. Germany as a fully developed country produces the most meat and animal products, including an incredible amount of milk, and Hungary and Romania have the right to reach such development also.

It would make sense that an increase in exports minus imports is in accordance with an increase in nutrient surplus applications to agricultural soils. Interestingly though, when taking a closer look at what products are contributing the most to these excess in exports, the largest contributor by far to Germany's exports is oilseed cake meal. 200kt of N or 2.4 kg N per capita is exported from Germany, however and even higher 238 kt of N in oilseed cake meal is imported into Germany. The difference of about 38 kt of nitrogen in this product is used in Germany's feedstuffs. According to the data from the FAO database, no oilseed is grown in Germany. This needs to be taken a closer look at but further proves the question regarding productivity. Germany's excess in exports versus imports comes from meat and milk (141kt of milk produced overall). Looking at Germany's total feedstuff values, which stand at 30 kg N per capita versus 16 kg N per capita in Hungary it can be argued that Germany's higher nutrient surplus value is going to the growing and imports of feedstuffs, contributing to it's much higher meat and animal product value.

Hungary's exports exceed it's imports in a much more clear fashion. These exports were split between wheat of which 19 kilo tonnes of N (1.8 kg/ca) /4kt of P (0.4 kg/ca) were exported and comparatively almost none was imported. Maize was the other product majorly exported in Hungary at 24 kt of N (2.3 kg/ca) and 6 kt of P (0.6 kg/ca). Only about 90 tonnes of N content in maize was imported. This was almost exclusively used for animal feed, with only a few tonnes going to human consumption.

It is clear that more research needs to be done regarding where exactly each countries imports go. It was not clear in the data used for this study what part of overall imports was used for feedstuffs. The one clear observation that can be made is when the overall balance is observed, Germany's imports of mineral fertilizer and plant and animal products are much higher. Given Germany's much higher production of livestock, it can therefore be assumed at this stage that the higher quantity of imports goes to the feeding of livestock. It is upon this assumption that a conclusion will be made.

Final Indicator

Of all of the above indicators discussed a possibility could be further analysed as a potential indicator given the data that is available. First of all though as was mentioned earlier in this section nitrogen and phosphorus behave differently, which should be appropriately reflected in the chosen indicator. In the case of nitrogen, losses to the environment must be controlled. In the context of this study this includes losses to surface waters and ground waters, and NH_3 emissions. Denitrification is an unpredictable processes to analyse. As far as NH_3 emissions are concerned, this is a source of pollution that can be controlled through the proper storage and handling of manure and should considered as a necessary measure in future policies.

It is clear that the first potential indicators discussed above are inappropriate due to the differing rates of denitrification and recharge groundwater rates between countries, which would cause an inevitable bias. The most promising indicator given the data available for this study seems to be the ‘surplus’ nutrients applied to agricultural soils, defined as all nutrient inputs to agriculture minus plant and feedstuff products. Excess nutrients were predominated by mineral fertilizer and manure and feedstuffs were much higher in Germany whom produces much more meat and animal products, particularly milk. Keeping this in mind, a cap could be put on the imported quantity of mineral fertilizer and feedstuffs to agriculture. Again, more research needs to be done regarding specifying where these surplus imports go. It is already known that more nutrients are applied to Germany’s soils that it needs through manure from its livestock most likely due to its huge dairy cow population. If this could be more efficiently managed, fewer imports of feedstuffs would be necessary, and this agricultural surplus, and therefore losses to surface waters would be curtailed. This ‘cap’ needs to account for the fact that Romania and Hungary should be able to develop a certain amount of livestock per capita. A specific amount cannot be discussed here.

Per capita and yr or per hectare and yr?

This agricultural surplus indicator tends to act more fairly when looked at per capita as it takes population density into account. This limit should be set so that each country should also be able to export a certain amount of plant and animal products however. This is where the per hectare and yr values would be 'fairer' for countries with less dense populations. Countries such as Romania with a lower population density could take advantage of this and increase productivity so that it could export as much as Germany for example. Perhaps the fairest way to deal with this conflict in interest would be to set a limit of excess imported feedstuff and mineral fertilizer nutrients per capita and per hectare, and depending on the countries situations, they could decide which one would suit them best. This way Romania for example could choose to set a per hectare cap and increase its exports whereas Germany could choose a per capita one.

2. Burden Sharing

As far as a fair 'cut' of emissions into the Black Sea, a specific value is beyond the scope of this study. Several things need to be kept in mind however when regarding the distribution of agricultural productivity across regions. As described in the Danube Study on pollution trading and corresponding economic instruments for nutrient reduction, three notions are identified to distribute fairness: equality, equity and exemption. These can be combined in order to fairly consider the situations in all of the countries within the Danube Basin.

Equality, meaning all parties have an equal responsibility to produce agricultural products relative to a given baseline can be applied to groups of countries that are considered equal in certain respects. In the case of this study, surplus N emissions onto agricultural soils per capita were found to be the qualities separating countries like Germany from those such as Romania. This observation correlated positively with the amount of exports minus imports. Equality therefore in the context of this study would imply that each country has the right to produce the same amount per capita, and export the same amount per capita.

At a last resort where equity and equality both result on an unfair burden on the poorest countries, the principle of exemption can be implemented where these countries are exempted from an obligation where it is not fully compensated.

To put the above considerations into this indicator perspective, the more nutrients that are lost from agricultural soils, the more mineral fertilizer and imported feedstuffs are consumed. An increase in fertilizer produced and imported in this study results from the need to increase feedstuffs for a higher livestock population. On the other end of the scale as can be seen in Romania's case, a lack of nutrients is apparent as it needs to import more than it exports to sustain it's livestock population. It's lack of nutrient application and losses to surface waters agree with this.

CONCLUSION

The original aim of this study was to develop different approaches for the definition of indicators and discuss their applicability as a benchmark of national nutrient management in respect to environmental protection in general and protection of Western Black Sea coastal areas from eutrophication specifically. This was accomplished through the development of nitrogen and phosphorus balances in Germany, Hungary and Romania. Upon close analysis of the results, the most nitrogen applied to agricultural soils came from mineral fertilizer and manure respectively. When this flow was followed through to surface waters, the percolation to groundwater flow contained the most nitrogen, whereas wastewater tended to carry the most phosphorus, followed by erosion of agricultural soils to surface waters. As the focus in this paper is on diffuse sources however, the percolation from agricultural soils flow was the one further analysed as a possible indicator for nitrogen, and erosion from agricultural soils for phosphorus.

Efficiency of nutrient management as far as the total contribution and losses from each country was compared. When nutrient surpluses were calculated for agriculture for each country Germany dominated per ha followed by Hungary then Romania. Figure 19 illustrates the large amount of meat and animal products produced by Germany compared to Hungary and Romania. A huge amount of milk products is included in this, which is a large source of nutrient emissions via manure. This accounts for Germany's high nitrogen losses to surface waters. It is assumed that Germany emits less phosphorus due to more efficient waste management processes and a decreased phosphorus stock compared to Hungary (**Figure 22**). Hungary applies a large amount of phosphorus fertilizer, accounting for it's large phosphorus stock per capita. It is previously noted (Csatho et al, 2007) that Romania's housed livestock population and lack of manure management accounts for much of its emissions. Hungary's geology allows for more nitrogen retention, explaining it's lower nitrogen emissions.

It was concluded given Germany's large meat and animal product value, and resulting high losses to surface waters, that a 'surplus' in nutrient emissions could be defined. The one noticeable difference between Germany and its neighbours in this study was the larger production of meat and animal products, accompanied with a much larger import of mineral fertilizer and plant and animal products. This surplus can therefore be defined as total input nutrients onto agricultural soils minus the products this produces. It is concluded that the exact amount of nutrients needed for this livestock needs to be further attained. A 'cap' could be consequently applied both per capita and per hectare to mineral fertilizer and feedstuff imports giving the country in question the final choice.

Nutrition and feeding management to reduce nutrient excretion is a powerful and cost effective approach to minimize the imbalance between P & N inputs and exports and reduce nutrient losses from farms. Better understanding of the P &N requirements of dairy cows in particular, and reducing the nutrient content of diets to true requirements will reduce P & N excretion from soils into surface waters.

Where the EU Water Framework Directive is concerned and more specifically the River Basin Management Plan in the case of the Danube, cooperation is vital on a Basin scale. A consistent, transparent and reliable nutrient balance should be maintained for all countries in order to fairly and effectively mitigate nutrient pollution in the Danube River, it's tributaries and finally into the Coastal Black Sea.

Future recommendations for further research and policy measures are as follows:

- As far as a fair distribution of measures is concerned, the nutrient surplus through the application of imported mineral fertilizer and feedstuffs to agriculture as a whole could be focussed upon. A future indicator should focus on establishing a set requirement of nutrients through imports of mineral fertilizer and feedstuffs for livestock both per capita and per hectare. Production of more specific data needs to be attained in this respect.
- An increased livestock density is accompanied with increased ammonia emissions from manure. As these emissions have to potential to travel and affect water quality elsewhere, all future policies should include strict requirements regarding the storage and application of manure.
- The methodology for nutrient balances must be consistent for all countries. However, attention must be paid to nitrogen coefficients in each country as livestock in Western European countries tend to be fed more nutrient rich fodder compared to livestock in CEE or NEU12 countries.
- As the percolation from agricultural soils flow for N and erosion flow for P was found to contain the most nutrients, future mitigation decisions should keep a variety of conditions in mind. These flows behave differently depending on soil type, amount of precipitation and hydrology, and land use.

Bibliography:

Ærtebjerg, G., Certensen, J., Casartelli, S., Dahl, K., Druon, J., Hansen, J., Kunitzer, A., Nygaard, K., Rygg, B., Schiller, C., Schrimpf, W., Severinsen, G., Sorensen, K.. (2001): Eutrophication in Europe's coastal waters. Topic report 7/2001. European Environment Agency, Kogens Nytorv 6, DK-1050, Copenhagen K. https://reports.eea.europa.eu/topic_report_2001_7/en, 166pp.

Bacchini, P., Brunner, P.H.. (1991): Metabolosm of the Anthroposphere. Swiis Federal Institute of Technology Zurich (ETH) Institute for Aquatic Sciences and Water Pollution Control c/o EAWAG 8600 Dübendorf Switzerland.

Beaugrand, G.. (2004): The North Sea regime shift: evidence, causes, mechanisms and consequences. Progress in Oceanography 57, 193-215.

Berhardt H., (2008): MONERIS calculations for PM-EG of ICPDR, version 2.02.

Brouwer, F.. (1998) Nitrogen balances at farm level as a tool to monitor effects of agri-environmental policy. Nutrient cycling in Agrosystems 52, 303-308.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, A.N., Sharplez, A.N., Smith, A.H.. (2008): Non point pollution of surfacewaters with Phosphorus and Nitrogen. Ecological Applications, Vol. 8, no, 3, 559-568.

Csathó, P., Sisak, I., Radimsky, L., Lushaj, S., Spiegel, H., Nikolova, M.T., Nikolov, N., Cermak, P., Klir, J., Astover, A., Karklins, A., Lazauskas, A., Kopinski, J., Hera, C., Dumitru, E., Manojlovic, M., Bogdanovic, D., Torma, S., Leskosek, M., Khristenko, A.. (2007): Agriculture as a source of phosphorus causing eutrophication in Central and Eastern Europe. Soil Use and Management 23, 36-56.

Csathó, P., Radimsky, L.. (2009): Two Worlds within EU27: Sharp Contrasts in Organic and Mineral Nitrgoen-Phosphorus Use, Nitrogen-Phosphorus balances, and Soil Phosphorus Status: Widening and Deepening Gap between Western and Central Europe. Communications in Soil Science and Plant Analysis 40, 999-1019.

Daskalov, G.M.. (2002): Overfishing drives a trophic cascade in the Black Sea. Marine Ecology Progress Series 225, 53-63.

Dombrowsky, I.. (2008): Institutional design and regime effectiveness in transboundary river management – the Elbe water quality regime. Hydrological Earth System Sciences 12, 223-238.

Elofsson, K., Folmer, ., Gren, I.. (2003)a Management of eutrophicated coastal ecosystems: a synopsis of the literature with emphasis on theory and methodology. Ecological Economics 47, 1-11.

Elofsson, K.. (2003)b: Cost-effective reductions of stochastic agricultural loads to the Baltic Sea. Ecological Economics 47, 13-31.

Folmer, H., de Zeeu, A..(2000): International environmental problems and policy. In: Folmer, H., Gabel, H.L. (EDs), Principles of Environmental and Resource Economics. Edward Elgar Publishers, Cheltenham, pp. 447-479.

Fröschl, L., Pierrard, R., Schönbäck, W.. (2008): Cost-efficient choice of measures in agriculture to reduce the nitrogen load flowing from the Danube River into the Black Sea An analysis for Austria, Bulgaria, Hungary and Romania. Ecological Economics 68, 96-105.

Gren, I.-M., Destouni, G., Scharin, H.. (2000): Cost effective management of stochastic coastal water pollution. Environmental Modelling and assessment 5, 193-203.

Institute for Water Quality and Waste Management, Vienna University of Technology and Department of Water and Wastewater Engineering, Budapest University of Technology (1997): : Nutrient Balances for Danube Countries – Final Report.

Kroiss, H.. (2005): Nutrient Management in the Danube Basin and it's Impact on the Black Sea – daNUbs Final Report Institute for Water Quality and Waste Management, Vienna University of Technology. March 2005.

Kroiss, H., Zessner, M., (1998): Nährstoffbilanzen der Donauanrainerstaaten Erhebung für Österreich. Institut für Wassergute und Abfallwirtschaft der TU Wien.

Lampert, C., Zessner, M., Kroiss, H.. (2004): Danube Study on pollution trading and corresponding economic instruments for nutrient reduction. UNDP/GEF Danube regional Project.

Margesson, Rhonda. (1997): Environment and International Water Management: Dealing with the problems of the Danube Delta. Environmental Impact Assessment Review 17, 145-162.

McQuatters-Gollop, A., Gilbert, A.J., Mee, L.D., Vermaat, J.E., Artiolo, Y., Humborg, C., Wilff, F.. (2009): How well do ecosystem indicators communicate the effects of anthropogenic eutrophication? Estuarine, Coastal and Shelf Science 82, 583-596.

Mylopoulos, Y., Kolokytha, E., Kampragou, E., Vagiona, D.. (2008): A Combined methodology for Transboundary River Basin Management in Europe. Application in the Nestos-Mesta Catchment Area. Water Resources Management 22, 1101-1112.

OECD (2008): – Country trends of environmental conditions related to agricultural since 1990. 210-335

OECD & EUROSTAT (2007): Gross Nitrogen Balances Handbook

OECD (2000): Special session on Material flow Accounting, Papers and presentations.

O'Shea, L., Wade, A.. (2009): Controlling nitrate pollution: An integrated approach. Land Use Policy 26, 799-808.

Romstad, E.. (2003): Team approaches in reducing nonpoint source pollution. Ecological Economics 47, 71-78.

Schreiber et al.. (2003): Harmonised inventory of point and diffuse emissions of Nitrogen and Phosphorus for a transboundary river basin; on behalf of the federal environmental agency, Berlin; Research Report 200 22 232.

Schlesinger, W.. (2008): On the fate of anthropogenic nitrogen. Proceedings of the National Academy of Sciences 106, 203-208.

Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleinman, P.J.A., Gburek, W.J., Moore, P.A., Mullins, G.. (2003) Development of phosphorus indices for nutrient management planning strategies in the United States. Journal of Soil and Water Conservation 58, 137-152.

Smith, V.H., (2006): Responses of estuarine and coastal marine phytoplankton to nitrogen and phosphorus enrichment. Limnology and Oceanography 51, 377-384.

Lottmann, J.H., Institute for Water quality and Waste Management, Vienna University of Technology. (2005): UNEP/GEF Danube Regional Project. Danube Study in Pollution Trading and Corresponding Economic Instruments for Nutrient Reduction. Final Workshop Report.

Van der keur, P., Henriksen, H.J., Refsgaard, J.C., Brugnach, M., Pahl-Wostl, C., Dewulf, A., Buiteveld, H.. (2008): Identification of Major Sources of Uncertainty in Current IWRM Practice. Illustrated for the Rhine Basin. Water Resource Management 22, 1677-1708.

Ward, F..(2009): Economics in integrated water management. Environmental Modelling & Software 24, 948-958.

Zessner, M., Lambert, C., Kroiss, H.. (2004): Nutrient Management in the Danube Basin and its impact on Black Sea Coastal Areas. Institute for water quality and waste management, University of Technology, Vienna, Austria.

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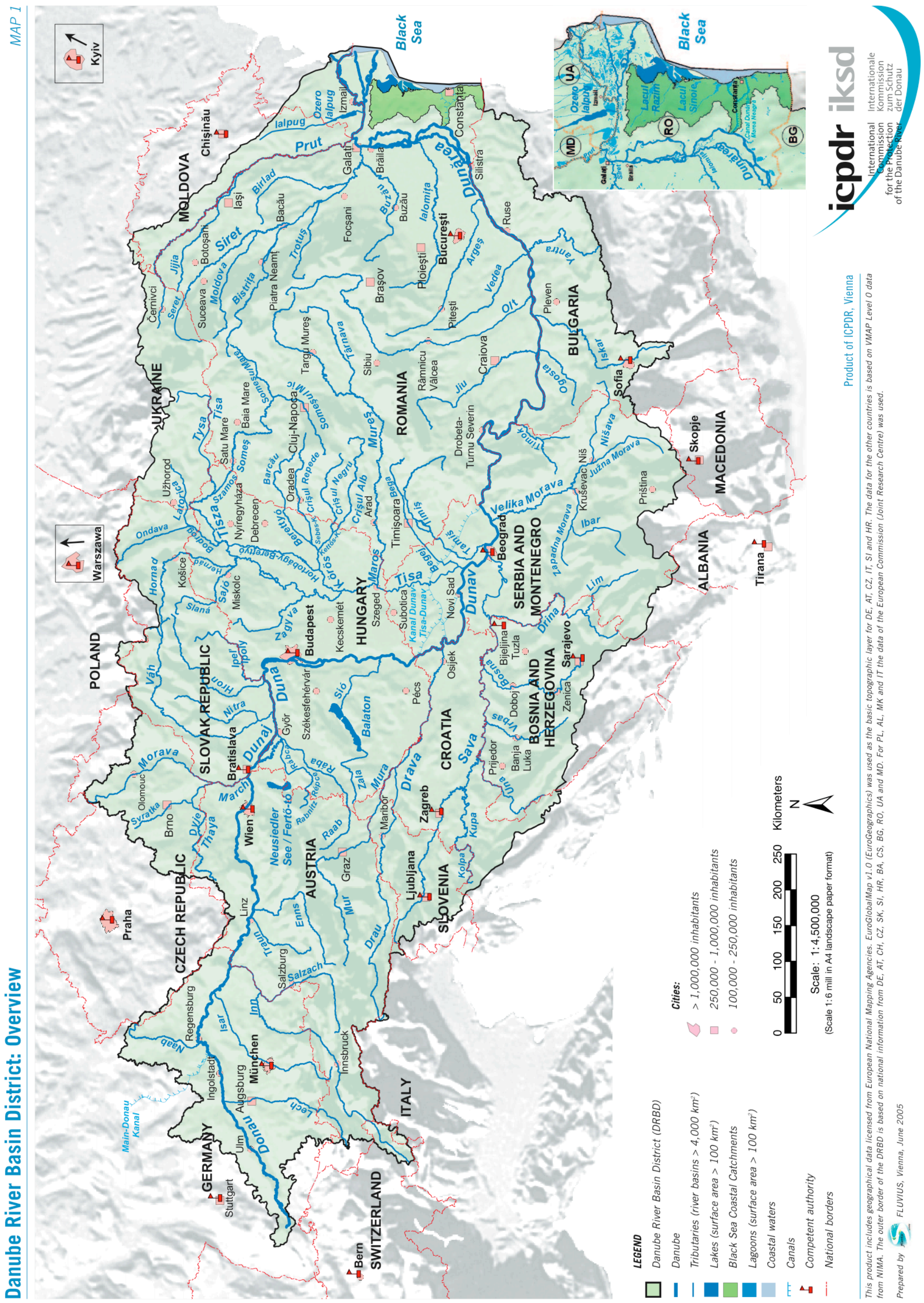
ANNEX

MAP: Overview of the Danube River Basin[8]



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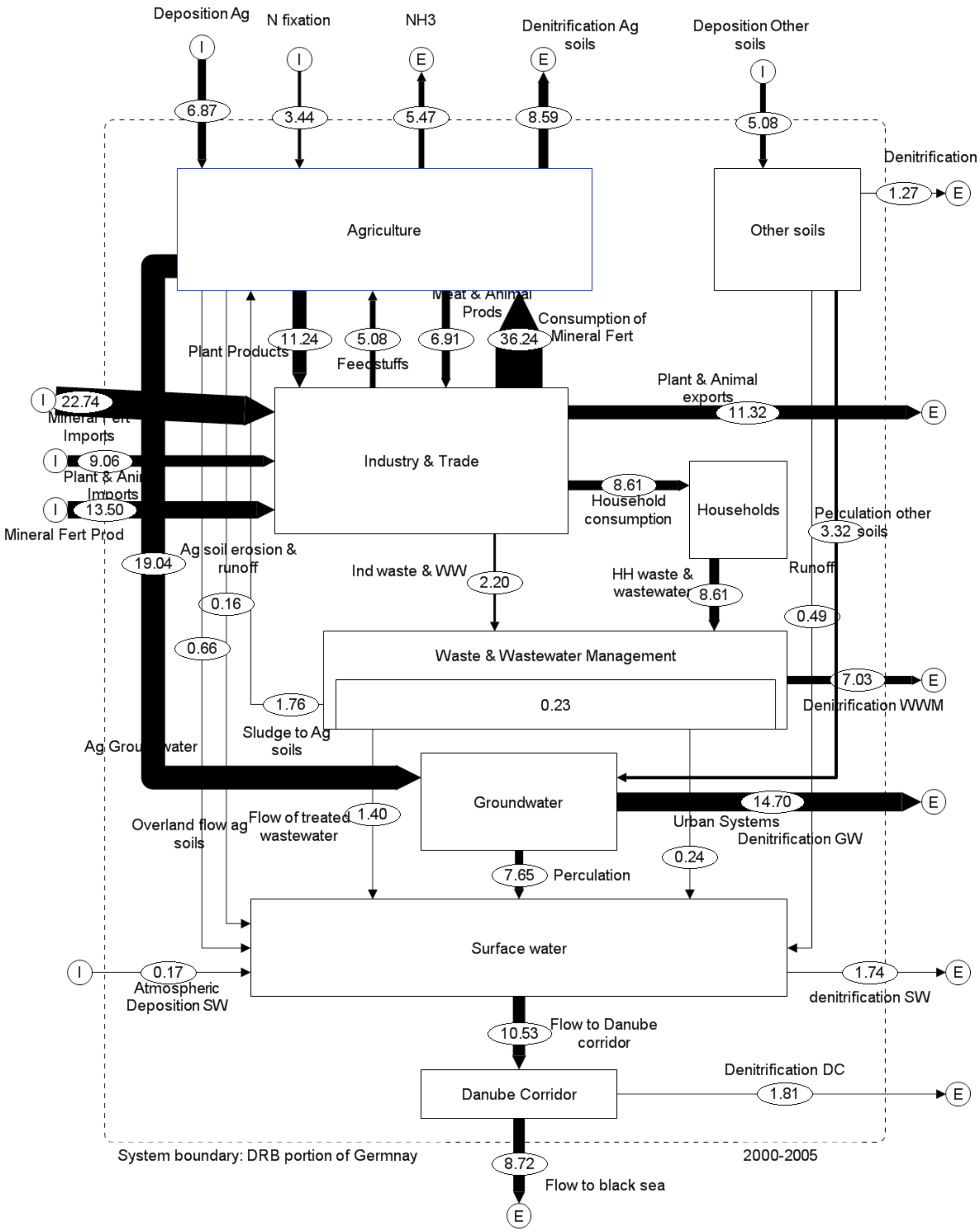
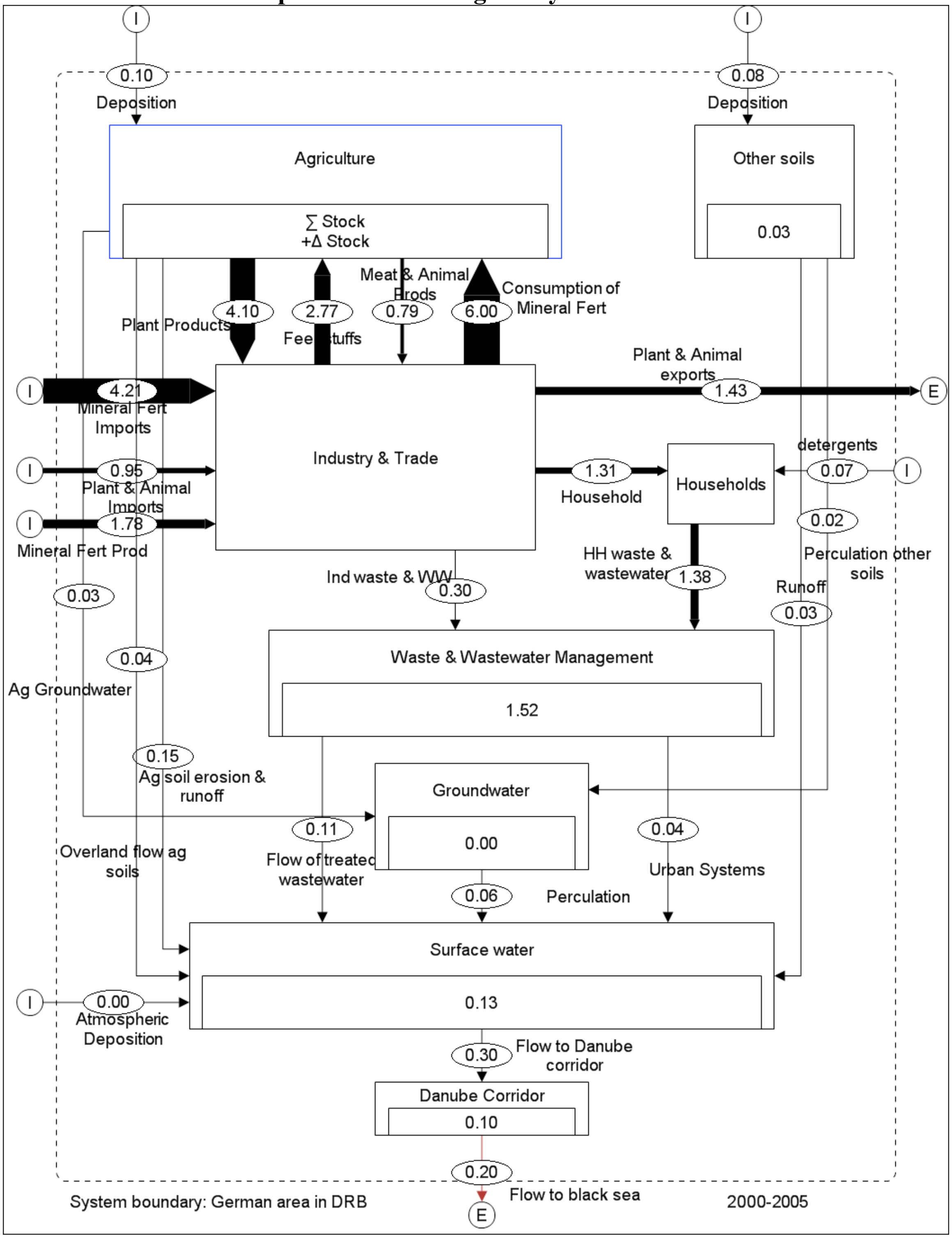
[8] ICPDR, www.icpdr.org; accessed June 10th, 2009

GERMANY: Total Nitrogen in Kg N/ca/yr 2000-2005

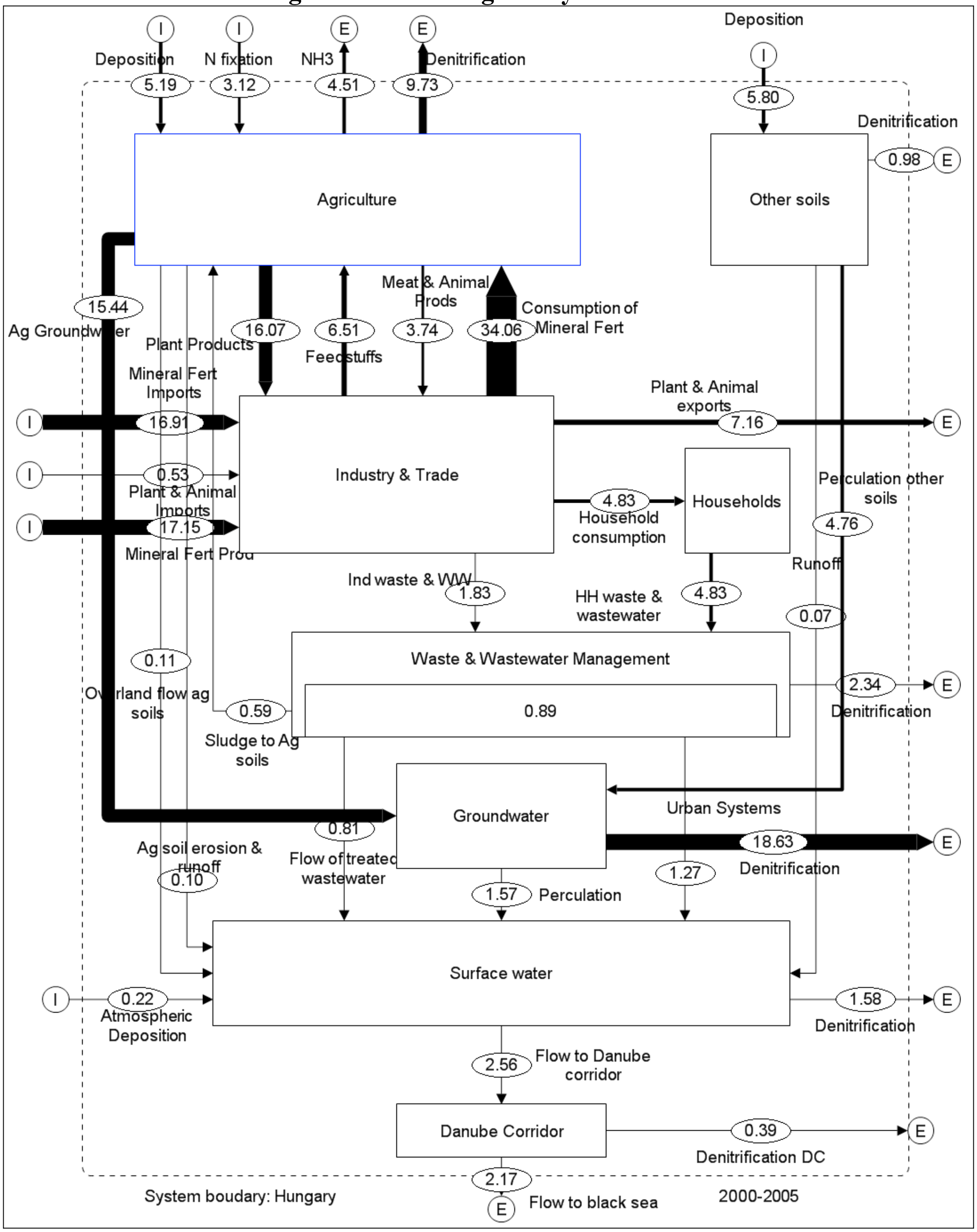


GERMANY: Total Phosphorus Balance kg P/ca/yr 2000-2005[9]

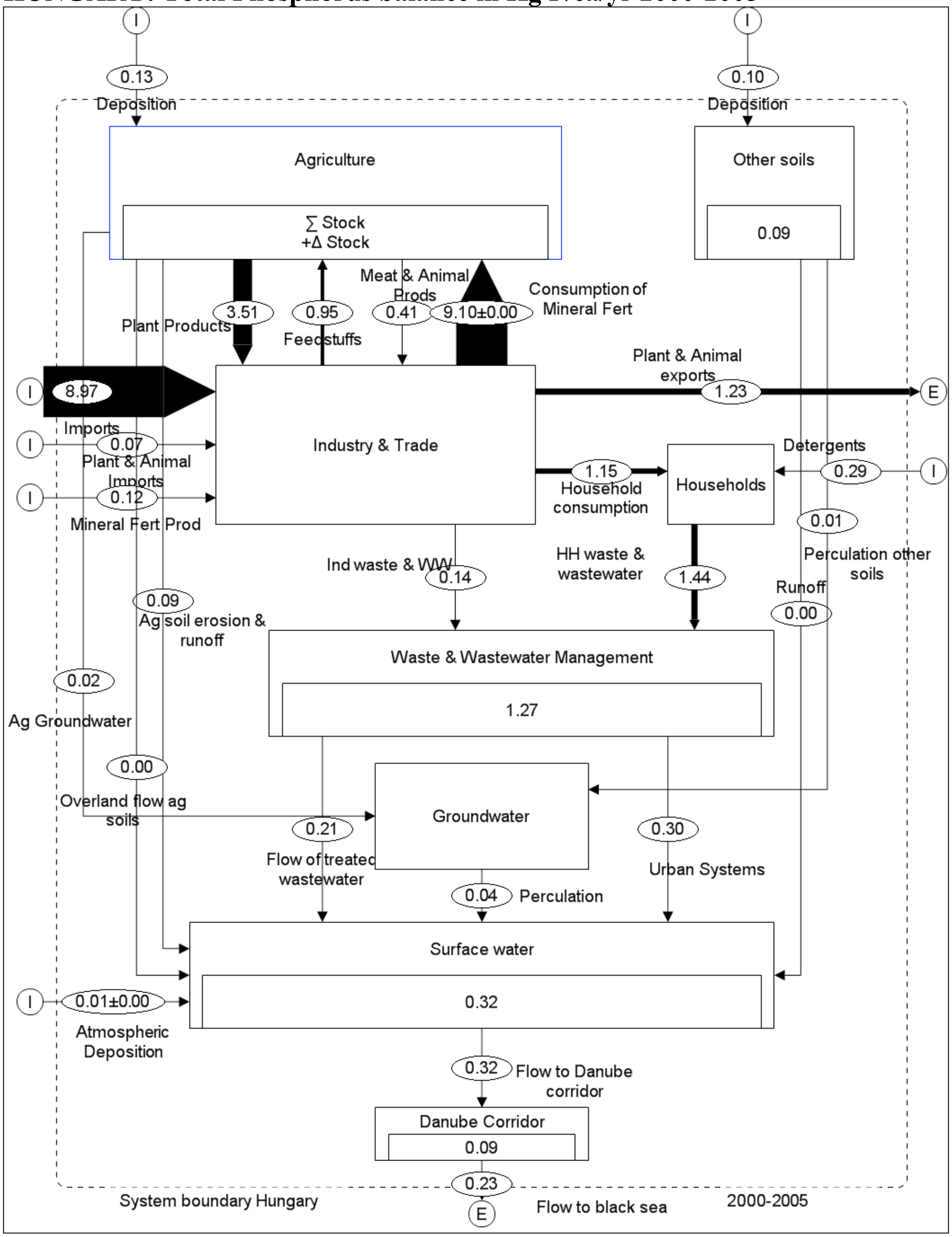


[9] Note: Change in stock agriculture: 3.76 kg P/ca/yr

HUNGARY: Total Nitrogen balance in Kg N/ca/yr 2000-2005

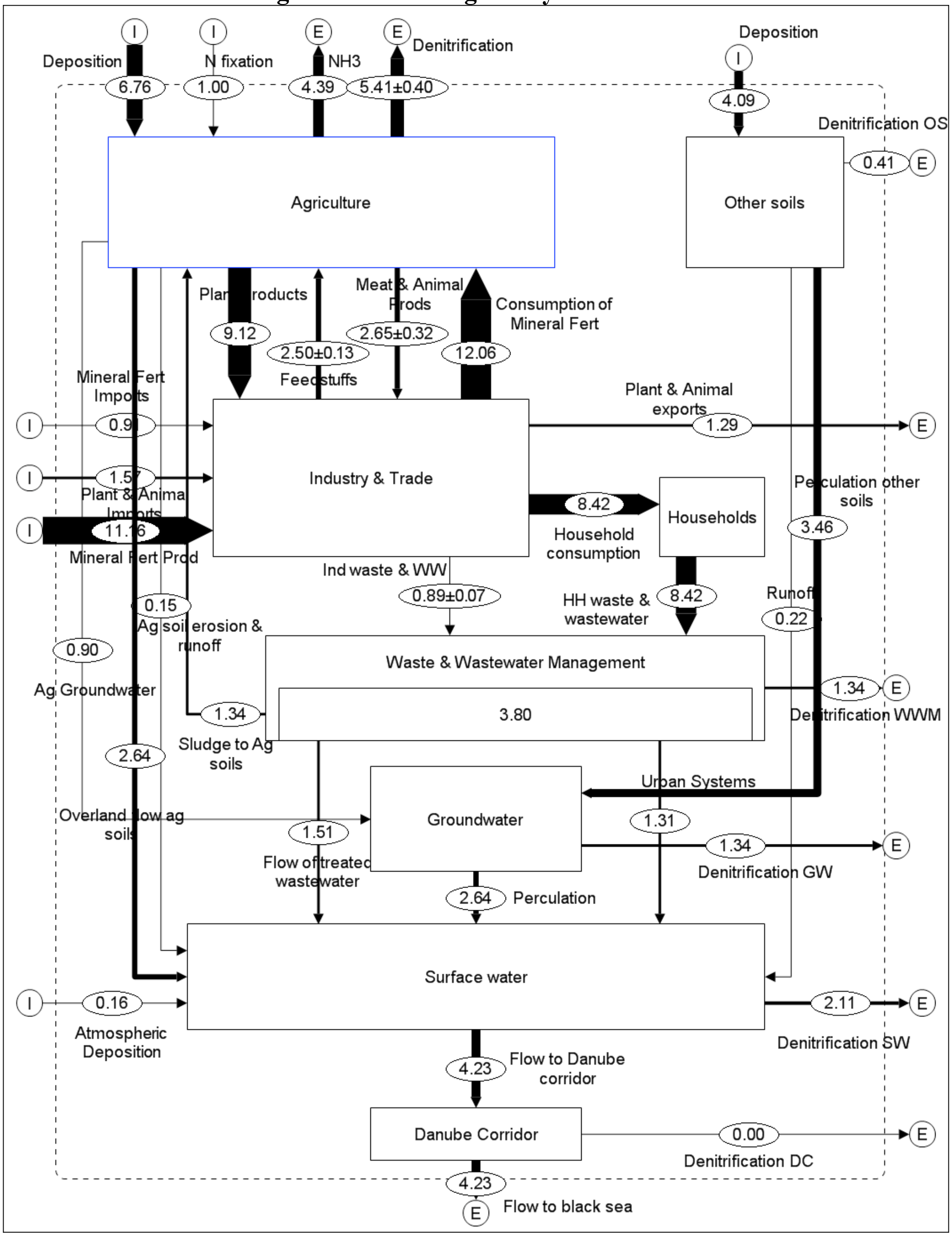


HUNGARY: Total Phosphorus balance in Kg P/ca/yr 2000-2005[10]

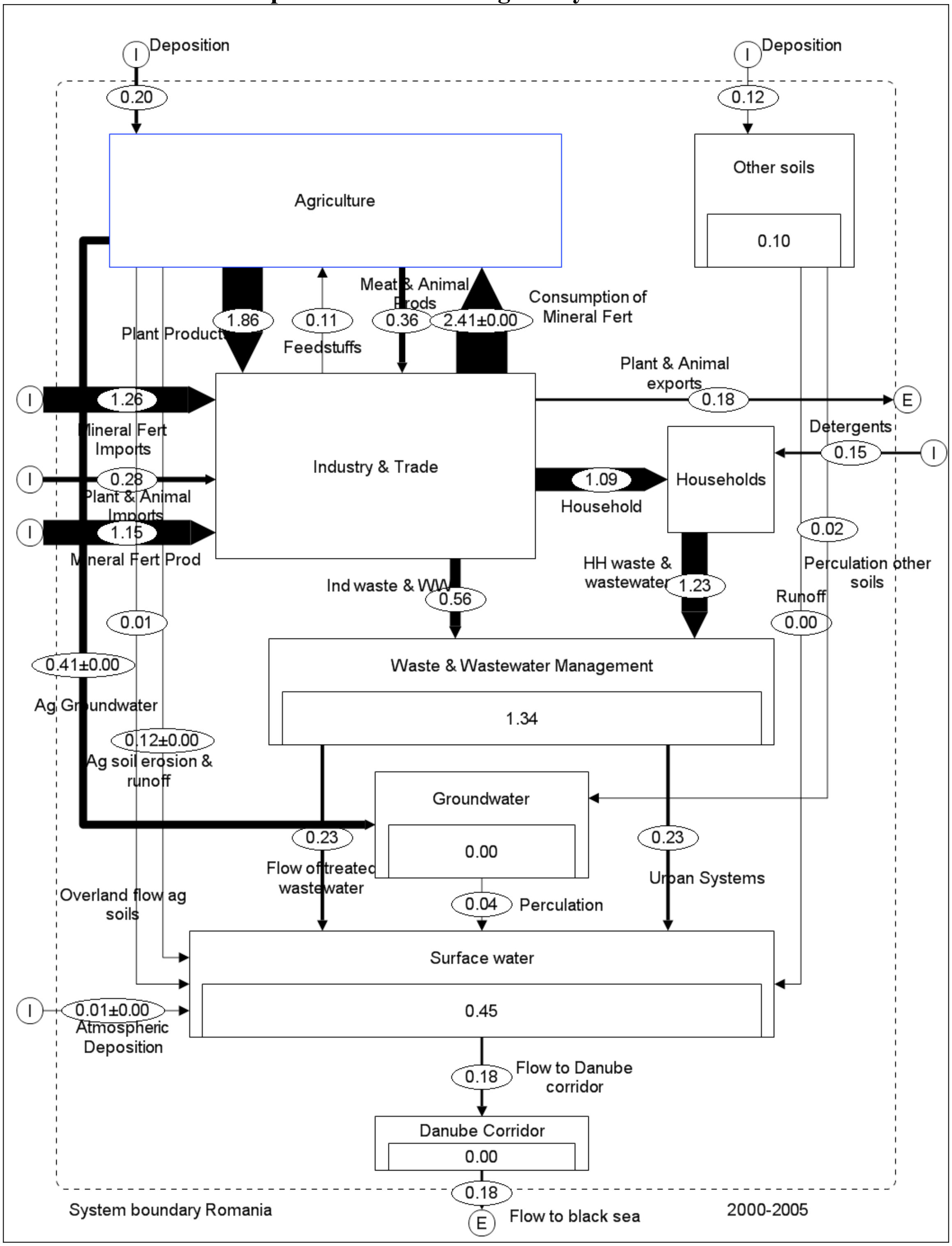


[10] Note: Change in stock agriculture: 6.14 Kg P/ca/yr

ROMANIA: Total Nitrogen balance in Kg N/ca/yr 2000-2005



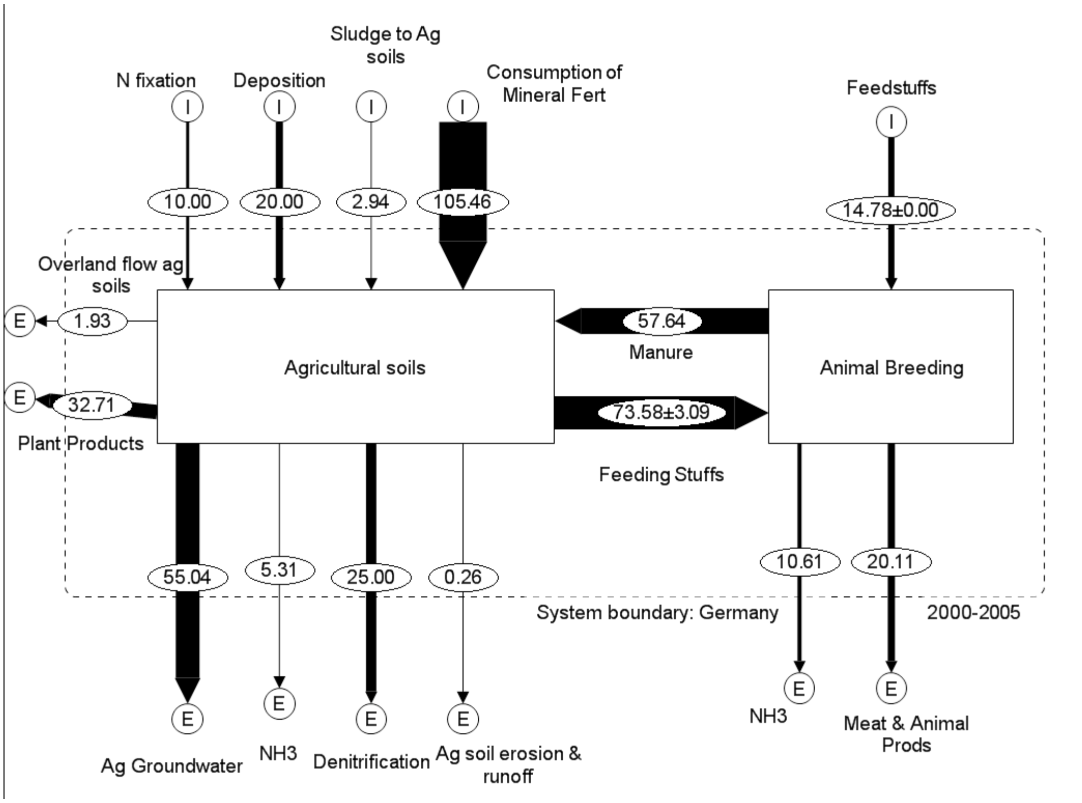
ROMANIA: Total Phosphorus balance in Kg P/ca/yr 2000-2005[11]



[11] Note: Change in stock Agriculture: 0.35 Kg P/ca/yr

GERMANY: Subsystem Agricultural Soils in Kg/ha/yr 2000-2005

NITROGEN:



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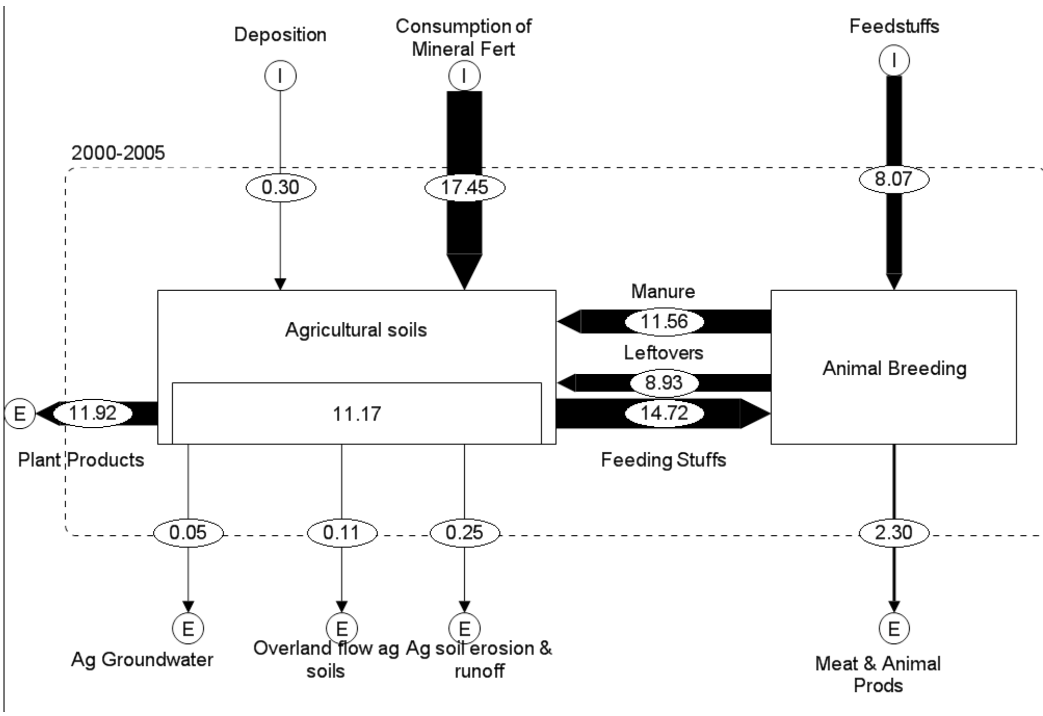
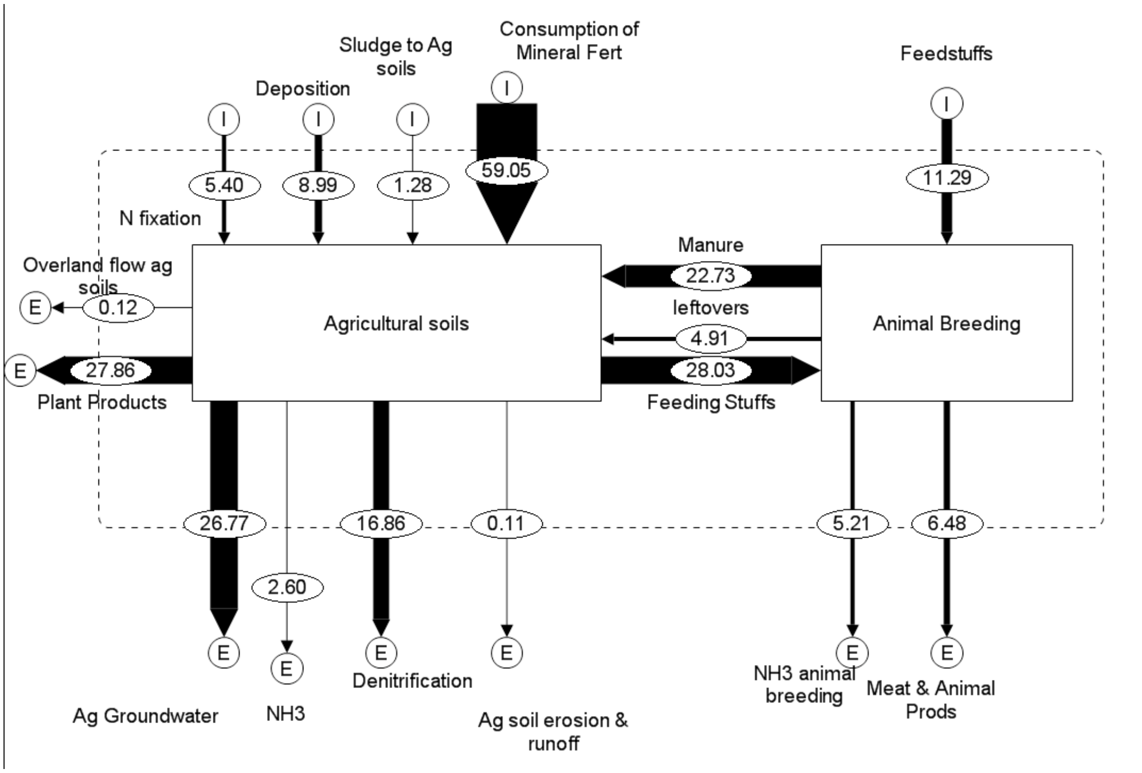


HUNGARY: Subsystem Agricultural Soils in Kg/ha/yr 2000-2005
NITROGEN:



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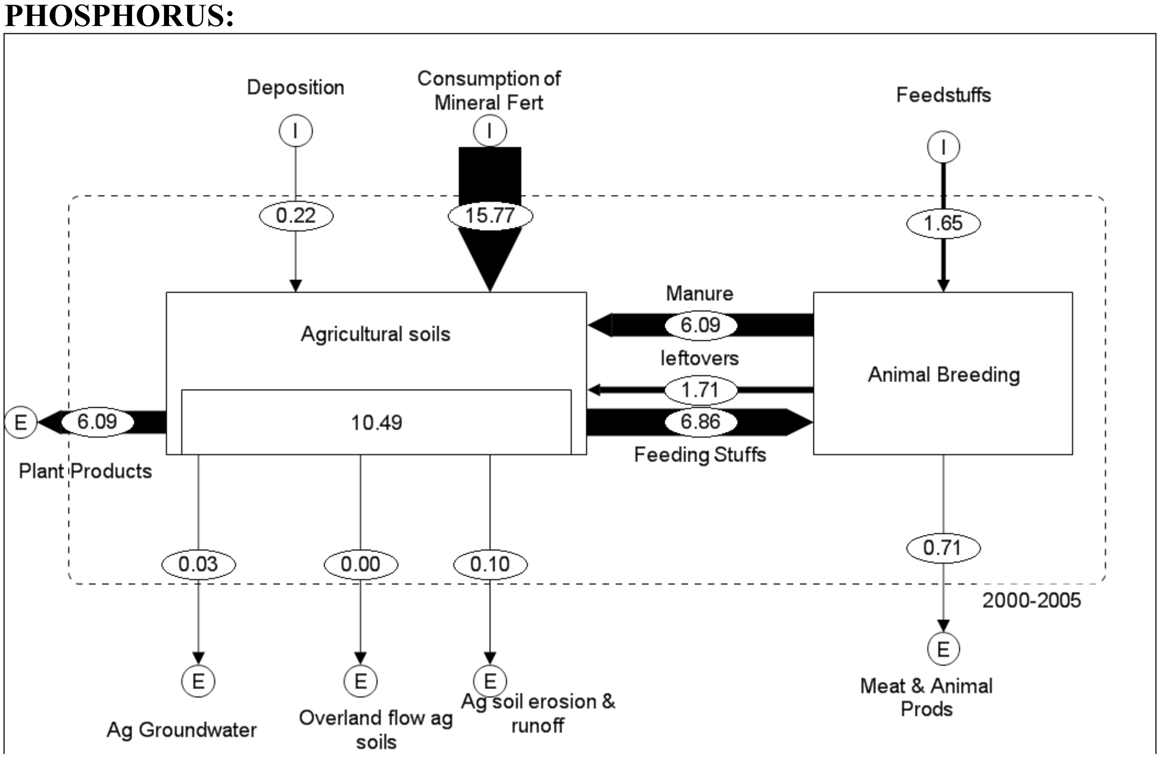
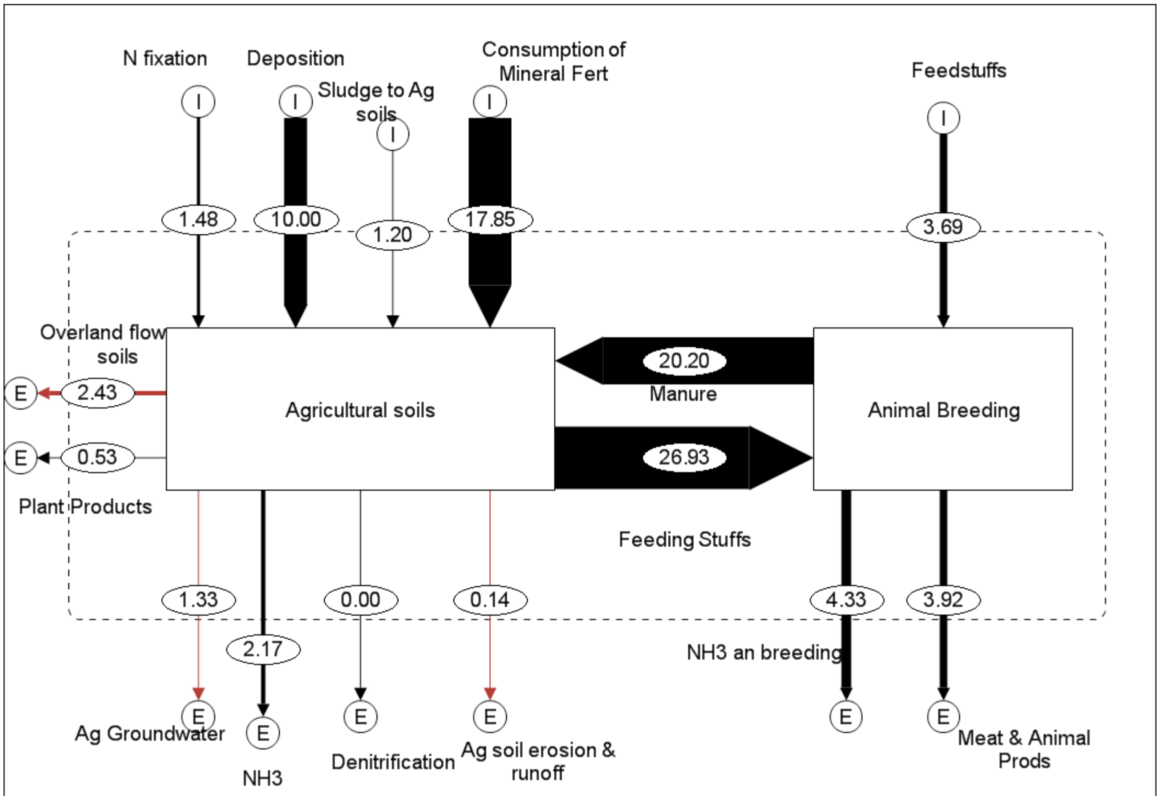


ROMANIA: Subsystem Agricultural Soils in Kg/ha/yr 2000-2005
NITROGEN:



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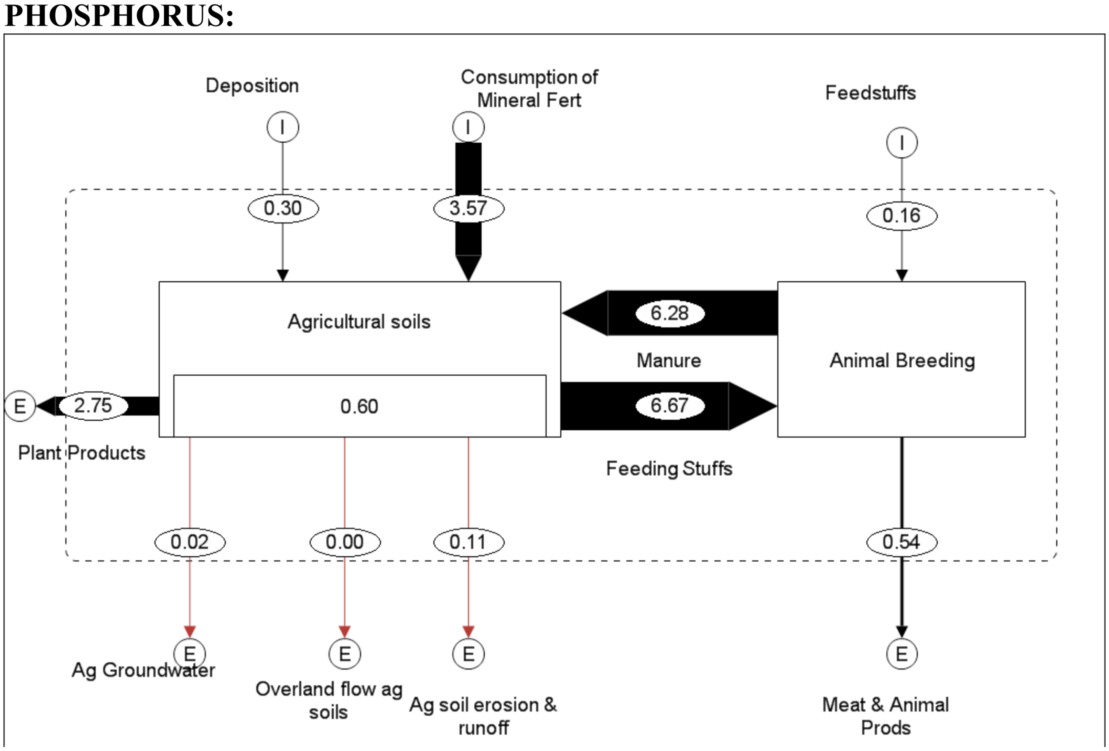
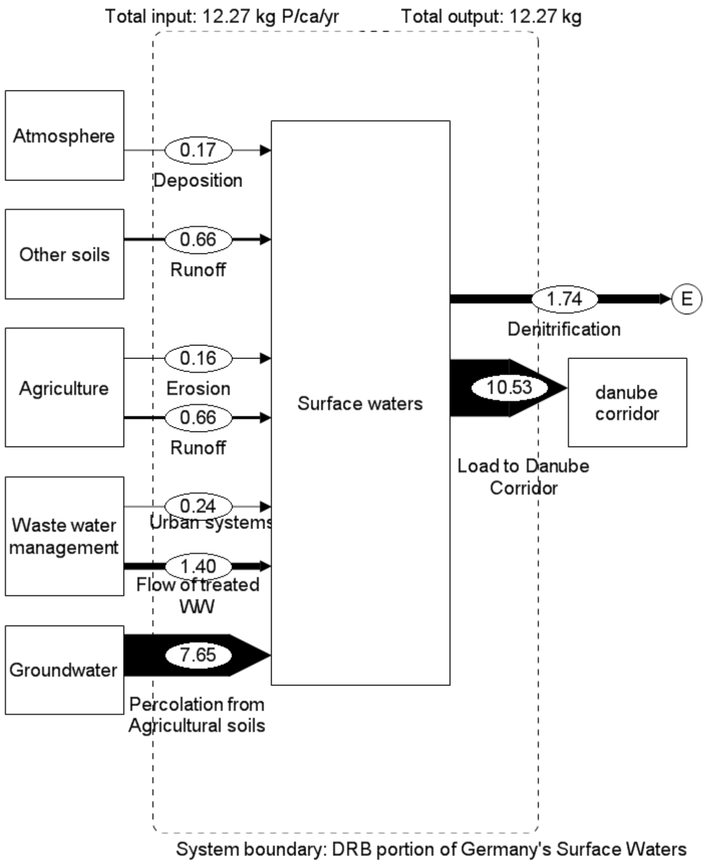
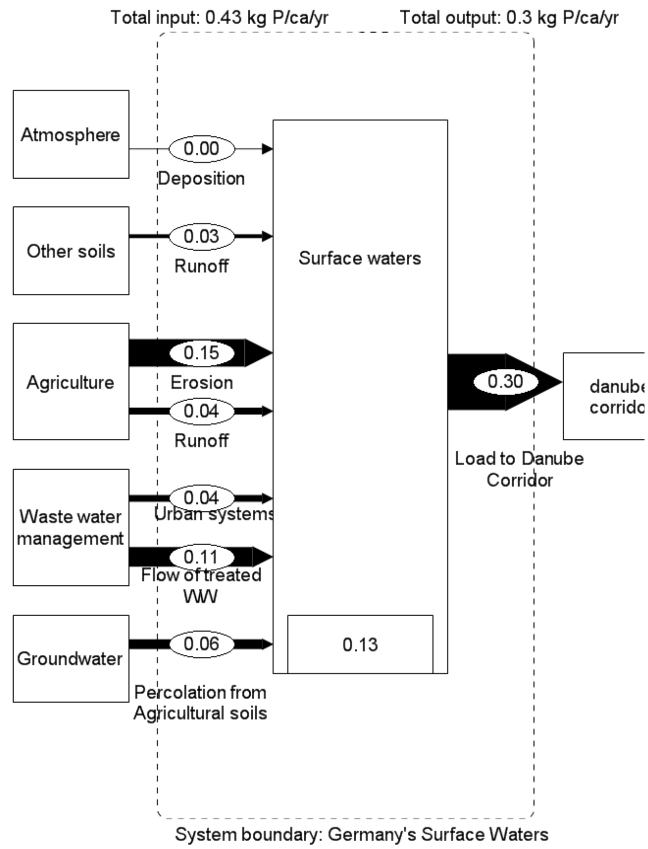


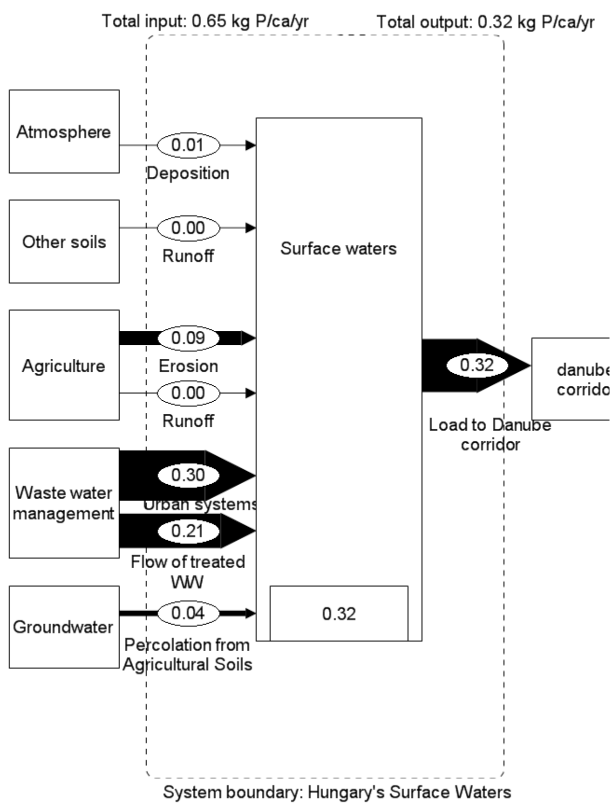
SURFACEWATERS:
GERMANY
Phosphorus: kg/ca/yr **Nitrogen: kg/ca/yr**

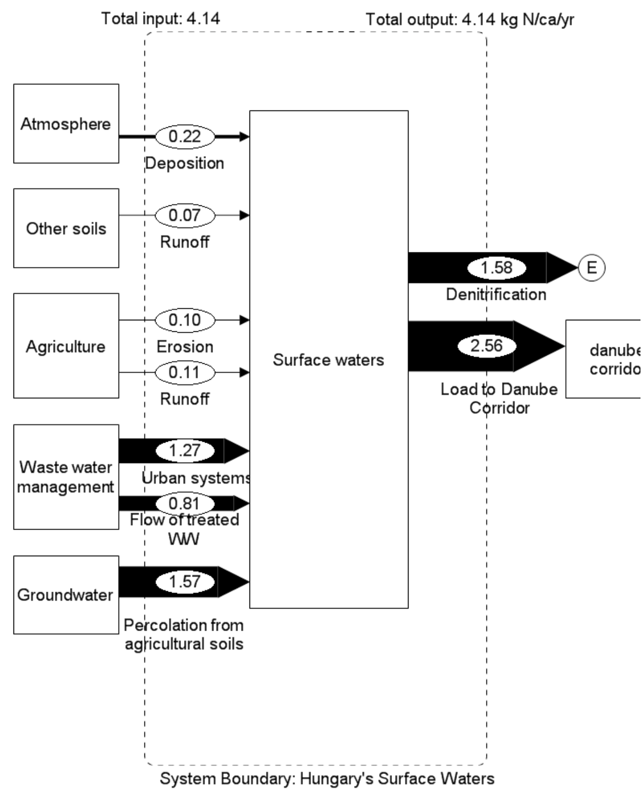




HUNGARY:

Phosphorus: kg/ca/yr **Nitrogen: kg/ca/yr**





ROMANIA:

Phosphorus: kg/ca/yr **Nitrogen: kg/ca/yr**