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MATERIALS ACCOUNTING AS A POLICY TOOL FOR NUTRIENT MANAGEMENT IN THE DANUBE BASIN

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ABSTRACT

Nutrient management has to consider both: Nutrients as essential elements for the biosphere with limited resources and nutrients as potential environmental pollutants (eutrophication, groundwater-deterioration). Materials Accounting techniques enable to describe and quantify the metabolism of Nitrogen and Phosphorus in large river Basins, such as the Danube Basin. By knowing the sources and pathways of nutrients it is possible (i) to identify the key causes of pollution problems and (ii) to point out inefficient use of the limited resource "nutrients". Additionally, it is possible to design efficient measures based on nutrient balances. Materials Accounting observes the changes of stocks within a time interval. Therefore, it allows the early recognition of the accumulation and depletion of harmful substances (e.g. Nitrate in the groundwater) or of limited resources (e.g. P in topsoils) in the environment. In combination with scenario development Materials Accounting has a high predictive power. There is a substantial difference in designing the most efficient measures for reducing nutrient inputs or to optimise the use of limited resources in the entire Danube Basin and in individual countries.

KEYWORDS

Danube; emission estimation; materials accounting; nutrient management; resource management; large river basins.

INTRODUCTION

High nutrient loads and their consequences are recognised as one of the most severe problems for rivers, lakes and the sea. Additionally, the resource "nutrient" can be limited either by their concentration in minerals (P) or the energy needed to produce mineral fertilisers (N). Therefore, nutrients have to be managed in view of environmental protection and of resource management. The base to develop a nutrient emission control policy for a river basin is to understand nutrient cycling in the environment and the anthroposphere. This means to know the major sources, stocks, sinks and pathways of nutrients within the catchment area. To recognise an inadequate use of limited resources and to detect the major nutrient emissions into the environment the methodology of Materials Accounting was applied. As a Case study region the river Danube Basin was chosen. Studies indicate that the evidence is overwhelming that a major part of the Black Sea is critically eutrophic (Mee, 1992). Additionally, the Danube Delta's lakes and secondary channels are in advanced state of eutrophication (Vadineanu *et al.*, 1992).

METHODOLOGY OF MATERIALS ACCOUNTING

Innovative materials accounting methods developed in the course of the past decade (see Baccini and Brunner, 1991) focus on the relevant processes[1] and corresponding flows and stocks of materials[2] within a defined system, such as a region. If the input[3] mass of goods into a process exceeds the output, a stock is formed. The flow of every material can be calculated using three types of information: (i) the mass-fluxes of the input goods; (ii) the substance concentration of the input good and (iii) the transfer function of this substance in each process. The materials accounting technique is usually carried out in five steps: definition of the objectives and questions; system definition; data acquisition and calculation; sensitivity analysis, presentation and documentation.

The analysis includes sources and sinks of materials. The interrelationship of the various processes (surface waters, groundwater, agriculture, waste water management, etc.) allows to identify the key causes of a certain pollution problem (eutrophication, groundwater pollution). Materials accounting allows to link the concentrations in the environment to the sources of pollution (Baccini and Brunner, 1991). This methodology serves well to identify and quantify the key causes for a certain pollution problem or for resource depletion. It is instrumental in the planning of remedial actions. In addition, since materials accounting observes the changes of stocks within a time interval, it allows the early recognition of the accumulation and/or depletion of harmful (nutrients as pollutants) or useful (nutrients as essential elements) substances in the environment. Hence, it is a valuable tool for environmental and resource management, and for the implementation of preventive strategies.

The "art" of materials accounting consists of finding the most efficient ways to determine material flows and stocks by measurements, literature values, expert advice, estimates etc. Often, national and regional statistical data are used for this purpose. Materials accounting is based on the principle of mass conservation: all material inputs, outputs and stocks of the investigated system must be in balance. In practice, due to problems of analyses and estimation, materials accounting hardly ever yields closed balances. However, the redundancy of information in a regional system usually allows us to decrease the uncertainty of the balance. It may also lower the amount of observations needed. Hence, monitoring by materials accounting techniques often yields more comprehensive information with less costs than direct monitoring (e.g. by soil sampling programs), certainly depending on the type of the problem.

CASE STUDY

During the years 1996 and 1997 the project "**Nutrient Balances for Danube Countries**" (Danube Applied Research Program, 1997) was carried out within the framework of the PHARE-program. The main objective of the study was to provide detailed nutrient (N and P) balances for the catchment area of the Danube. The assessment incorporated major sources, stocks, sinks and pathways of nutrients in the anthroposphere and the environment. It included nine riparian countries (excluding Serbia, Croatia, and Bosnia Herzegowina), and covered the two periods before and after the economic transition of 1988/9 and 1992. It was based on Materials Accounting techniques. In the following, results of this study will be presented and the usefulness of the Materials Accounting methodology for nutrient management will be pointed out.

For balancing the N and P-nutrient fluxes in the Danube Basin the following "processes" were considered: "surface waters", "groundwater", "wastewater management", "agriculture" (including soil), "water supply", "private household", "industry", "forestry" (including soil), "other soils", "waste management", "troposphere"; Water and water related fluxes - which were the main objectives of the study - were only one part of the system Out of these the most important processes concerning N and P were "surface waters",

[1] A "process" denotes the transformation, transport or storage of a good. Goods consist of substances or substance mixtures with functions valued by human beings (food, washing powder, sewage sludge, etc.).

[2] Chemical elements or their compounds are defined as "substances". They can be characterised physically, chemically and economically within goods.

[3] "Inputs" are material flows into a given process; material flows from a given process are called "outputs". Material flows into the defined system are called "imports", material flows which leave a given system are called "exports".

"groundwater", "wastewater management" and "agriculture". Only those material flows were investigated in detail, which proved to be important for the river Danube and the Black Sea.

To interlink the full balance and its water related components, water quality data was chosen. Three categories of data were used to develop material balances: (i) primary data (e.g. measurements of emission and of ambient water quality), (ii) secondary data (statistical information, administrative records, literature etc.) and (iii) tertiary information (such as expert knowledge).

This task was complicated due to two reasons:

- The uncertainty of emissions - independently how they were determined - was often so large, that a refinement by ambient water quality monitoring was not feasible. This applies to point sources with extremely scarce observations (e.g. annually two observations in many countries of the Danube Basin). The situation was even worse for diffuse sources, which could not be really analysed. The practice here uses unit areal loads as a basis for order of magnitude estimates.
- The fate of nutrients in surface waters is strongly influenced by many complex physical and biogeochemical, biochemical processes (sedimentation, resuspension, adsorption, nitrification, denitrification, algae uptake etc.). They significantly depend on hydrological and meteorological factors. These may not be properly reflected by observations available (e.g. one observation per month): the accuracy of annual (or multi-annual) nutrient load estimates for a given cross section, and their change for a particular region can be rather low. Additionally, these annual changes are due to two factors, emissions and "retentions" along the river stretch considered. There is a strong dependency of retention and loss processes on the specific run-off and the mean concentration (Behrendt, 1996). In the Case Study presented below, the retention was much smaller in countries characterised by intensive runoff and short residence time (e.g. Austria, Slovenia and Germany) than in others of low runoff coefficients and lowland nature.

In short, the difficulty in assessing uncertainty lays in (i) estimating emissions and (ii) estimating loads (the latter from immission data).

<u>Case study results</u>

All the results presented in this chapter stem from the project "**Nutrient Balances for Danube Countries**" (Danube Applied Research Program, 1997).

Surface waters. Materials accounting results of the Danube Basin show the importance of the agricultural sector: more than half of the nutrient emissions (P and N) originate from farming, about 20% stems from private households, and about 10-13% from industry.

The most important pathways are for phosphorus: direct discharges (33% of the total flow, predominantly from agriculture), erosion/runoff (31%, mainly agriculture) and effluents from sewage treatment plants (30%).

About 40% of the total P-emissions into surface waters originates from diffuse sources. The contribution of diffuse sources were defined as the ratio of: base flow + erosion/runoff + surface runoff from forests + storm water overflow + N-fixation in surface waters divided by the total input. Point sources were defined as the ratio of: effluents from waste water treatment plants + direct discharges from households + direct discharges from industry + direct discharges of manure divided by the total input.

For nitrogen the most important pathways are base flow (35%), direct discharges, erosion/runoff and sewage treatment plant effluents in similar shares, again agriculture being the source for more than half of N in many countries. Nitrogen emissions into the surface waters of most countries investigated stem primarily (60%) from non-point sources.

Table 1. Sources and pathways of P in the Danube Basin in the year 1992; total P: 105 kt

Phosphorus	Sources [in %]				
Pathways [in %]	Agriculture	Households	Industry	Others	**Total**
Erosion/run off	28	0	0	3	**31**
Direct discharges	18	6	6	3	**33**
Base flow	2	2	0	2	**6**
Sewage treatment plant	9	14	7	0	**30**
Total	**57**	**22**	**13**	**8**	**100**

Table 2. Sources and pathways of N in the Danube Basin in the year 1992; total N: 825 kt

Nitrogen	Sources [in %]				
Pathways [in %]	Agriculture	Households	Industry	Others	**Total**
Erosion/run off	17	0	0	4	**21**
Direct discharges	12	4	6	2	**24**
Base flow	17	4	0	13	**35**
Sewage treatment plant	6	10	5	0	**20**
Total	**51**	**19**	**10**	**19**	**100**

Groundwater. There were three main input flows of N into groundwater: percolation from (i) agricultural soils (about 50%), (ii) forestry soils (about 25%) and (iii) septic tanks (about 15%).

The increase of the N-concentration in groundwater is counteracted by the base flow into surface waters and denitrification processes. About 60% of the N input into groundwater is removed by denitrification in the Danube Basin. About 30% of the total N input leaves the groundwater via base flow. In most countries the input of N into groundwater is larger than the total output, thus the stock and the concentration of N increases. This means that (i) the quality of the water decreases and the emissions of N via groundwater will increase.

The importance of denitrification in groundwater (and soil) vary considerably from country to country. For some of the countries, the ratio of denitrification to total input was estimated below 15%, while for others it was above 65%. In countries with a low denitrification rate the contribution from base flow ranges from 45% to 65% of the total input, whereas a high denitrification rate leads to a N base flow lower than 30%.

About 50% of the N base flow is caused by percolation from agricultural soils. The total base flow contributes about one third of the total nitrogen input into surface waters. Thus, to minimise the N surplus in agricultural soils is an effective way to reduce N-emission into groundwater. Considering the stock of N that has been built up during the last decades, measures taken in agricultural practice will show delayed effects.

From the point of view of nutrient management, the denitrification process is a loss of a resource. The N-emissions due to denitrification are 15 to 30% higher than the N-amount contained in the animal products. From the point of view of environmental protection the conversion of nitrate into N_2 in the ground water body is an efficient "cleaning mechanism". Without the denitrification process the N-emission via base flow would be 3 times higher!

Waste water management. The nutrient load from waste waters is 400 kt of N and 80 kt of P. They are the second important input from the viewpoint of future emission reduction strategies. About 65% of the N and P stems from private households and the remaining 35% originate mainly from industrial waste water. Manure (60 kt N and 15 kt P) is also treated in agricultural wastewater treatment plants.

The overall removal efficiency from wastewater is 15% for N and between 15-20% for P. This is calculated as the sum of nutrient-removal through sewage sludge, the content of septic tanks applied on agricultural soils and emissions to the "troposphere" (i.e. denitrification, but it is of negligible importance inthe Danube Basin) divided by the total input.

From the remaining N and P, about 40-45% of the N and 55% of the P are discharged into surface waters via effluents from sewage treatment plants (including treated manure), about 20-25% of the N and P are discharged directly into surface waters, and about 30% of the N and 15% of the P percolate into the groundwater.

Hence, the nutrient removal efficiency of waste water management is rather low and far from any optimised nutrient management. The present waste water management emits large amounts of N and P to the environment (groundwater, surface waters) causing negative impacts and wasting nutrients. As in the process groundwater, denitrification processes yield in a loss of the resource N.

Agriculture. Prior to the economic transition, the total input into agricultural soils in the Danube Basin is estimated to about 115 kg N/(ha.y) and 27 kg P/(ha.y). This resulted in an increase of stock (total input minus total output) in agricultural soil of some 17 kg N/(ha.y) and 13 kg P/(ha.y).

During the economic transition, the total N and P inputs decrease by about 35% and 55%, resp.. This is mainly due to a decrease in the application of mineral fertiliser (55 and 65%, resp.). The application of manure drops by about 30%, as well. The nutrient up-take of crops decrease far less than the application (by about 20% for both nutrients). This is due to the nutrient-accumulation during the past decades, which created a large stock of N and P available for plants now. According to the agricultural balance, in 1992 there is only a slight increase in the stock of about 4 kg/(ha.y) for both nutrients in the Danube Basin.

Nitrogen losses from topsoils into the groundwater amount to 5 to 20% (in the mean 13%) of the total input into the soil. These losses indicate again possible harmful effects on the ground water quality.

Twenty to twenty-five percent of the total N and P loads of surface waters is due to manure discharges, 80% of which is emitted in Romania. In the future efficient policies and measures to manage manure in the agriculture are needed.

Nutrient balance scenarios for the year 2005 were prepared for agriculture. Two scenarios were considered: (i) Autonomous development (AD) and (ii) Best Available Practice (BAP) (both in terms of agricultural technology and economy).

The AD scenario foresees an increase of the total input of N and P primarily due to an intensified application of mineral fertiliser. Main output goods for N will be sold crops, which will increase slightly, and animal products which will increase by some 20%. Erosion/runoff, percolation into groundwater, and direct discharges of manure will also increase substantially. For P, similar developments can be noted. As a conclusion of the nutrient balances, the change of stock in 2005 will be by 120% for N and 140% for P higher than 1992 (corresponding to an enrichment of about 10 kgN/(ha.y) and 12 kgP/(ha.y)).

The BAP scenario also predicts an increase of the total input of both nutrients, nearly as much as for the autonomous development, mainly due to fertiliser application. For N the total output increases by about 20% and for P by 30%. For both nutrients animal production is predicted to be about 25% higher, and sold crops to be about 55% higher than in 1992. Erosion/runoff is predicted to drop, whereas N percolation from agriculture and direct discharges of manure will remain on the level of 1992. For N, there is a decrease in the change of stock by 40% (in comparison to 1992) which still causes an enrichment of about 3 kgN/(ha.y). P on the other hand shows an increase in stock by about 100% (10 kgP/(ha.y)).

The difference between the two scenarios is relatively small: BAP leads to a decrease of erosion/runoff and to a smaller increase in other balance components including soil stock increase. Both erosion/runoff and base flow are influenced strongly by nutrient stock in soil. Due to the stocks built up in the last decades, measures taken in agricultural practice to reduce nutrient losses will show delayed effects.

Nutrient emission reduction measures should focus on minimising nutrient surpluses in soils (optimised soil balances), erosion protection measures as well as reforestation of areas susceptible to erosion. Due to large stocks measures will have delayed effects. The discharge of manure should be reduced e.g. by the use of manure as fertiliser.

Discussion on uncertainty of case study results

The uncertainty of emission estimates of individual countries is around 50%. It is smaller on the total Danube scale and in countries with abundant data sets, such as Germany. Reasons are first the presence of large interacting fluxes which limits the strength of cross-checking. Second results, in which country emissions are basically "conventional wisdom" estimates derived by using simplified computational procedures and a number of assumptions for flows of goods (erosion, base flow, denitrification, etc.), as well as various factors influencing material flows (fertiliser application, manure production, their losses, estimation of stocks, nutrient content of soil, tightness of septic tanks etc.). In addition, good data is scarce in several sectors. However, due to lack of data, probably some of the assessments can be biased. The uncertainty in the quantification of the effects of management strategies for the agricultural sector on erosion/runoff and base flow is quite high. Therefore, the results obtained from the agricultural scenarios should be seen as a tendency and not as "real" values.

Available data on nutrient concentrations in surface waters is generally insufficient for estimating annual nutrient loads and therefore to recheck the results stemming from materials accounting estimates. From the view of materials accounting total Nitrogen and total Phosphorus concentrations are needed. The transport of total nutrients at high flow conditions might be important but is hardly known (see also Dolan *et al.*, 1981; Sheridan and Hubbard, 1987). Thus, for water quality monitoring it is recommended to put a much stronger focus on monitoring under various flow conditions at important sites (large tributaries, high emission zones, before and after river stretches with high sedimentation rates, country borders and at final discharge points into the Black Sea); It is important to keep the same standard of the sampling method and frequency over a longer period of time (years) and to improve the comparability of methods (sampling, sampling frequency and analysis). The relationship between nutrient-emissions and ambient water quality (load response relation or transfer coefficients) are not known for the river Danube.

CONCLUSIONS

Materials accounting methods allows us to describe and quantify the metabolism of N and P of large river basins, such as the Danube Basin. They are instrumental to identify the sources of nutrients and their pathways to the environment.

Additionally, the balances of individual processes indicate that resource management needs to be improved, especially in agriculture, but also in the waste water management sector. Improvement in the management is needed if nutrients are accumulated or if they are transferred into other environmental compartments or into compounds unavailable for plants.

Due to the large scale of the river Danube Basin, it is not possible to develop load response relations for short river stretches, but rather to define "water" nutrient balances for sub-basins, basins or a country.

As shown for the agricultural sector and for groundwater, Materials Accounting assesses the changes of stocks within a time interval. Therefore, it allows the early recognition of the accumulation of harmful substances (e.g. nitrate in the groundwater) or of limited resources (e.g. P in topsoils) in the environment. It is possible to depict annual changes in the stocks long before traditional monitoring methods show significant changes in stocks.

The observation of stocks is crucial. Measures taken in agricultural practice or in waste water management in order to reduce nutrient losses into surface waters (erosion) or into groundwater (percolation from soils or from septic tanks) will show delayed effects due to the stocks built up in the soils and the groundwater in the last decades.

Materials Accounting has a high predictive power in calculating scenarios. According to the agricultural scenarios developed (autonomous development and best available practice), the decrease observed from 1988/9 to 1992 of the diffuse flows of nutrients in the Danube Basin will be temporary only, and will be followed by a future increase. Thus, measures in municipal wastewater management and industry are important. More crucial is however, to develop an integrated nutrient management approach with a strong focus on agricultural non-point sources.

Available data on nutrient concentrations in surface waters is generally insufficient for estimating annual nutrient loads. Concentrations of total Nitrogen and total Phosphorus are needed as well as monitoring under various flow conditions at important sites. Additionally, the comparability of methods (sampling, sampling frequency and analysis) has to be improved. The relationship between nutrient-emissions and ambient water quality (load response relation or transfer coefficients) are not known for the river Danube. Therefore, by now the impact of a given emission reduction policy on the loads of the Black Sea is hard to estimate. Further research is needed.

The importance of various nutrient flows into "surface waters" from the riparian countries differ significantly depending on size, land use pattern, population density, level of wastewater management etc. Therefore, it is a substantial difference in designing efficient measures to reduce nutrient inputs for the entire Danube Basin or in individual countries. The same applies to the management of nutrients as a resource. Depending on the country, different measures have to be taken to optimise the use of limited resources.

For analysing long-term changes in nutrient conditions and developing an efficient monitoring of nutrient stocks and flows, it is proposed to establish national nutrient balances which are amended periodically. The monitoring points should be such that data can be collected with no additional measurements, e.g. at the point of sale (fertiliser, crop and food products) or in wastewater treatment effluents and sewage sludge.

If Materials accounting, ambient water quality data and geographic information systems (GIS) are combined, nutrient balances could be cross-checked and improved significantly. Additionally, results from scaling up by case study areas and from scaling down by national balances can be combined to improve the balances.

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