Pergamon

Wat. Sci. Tech. Vol. 40, No. 10, pp. 9–16, 1999

0273–1223/99 $20.00 + 0.00

PII: S0273-1223(99)00667-8

NUTRIENT BALANCES FOR DANUBE COUNTRIES: A STRATEGIC ANALYSIS

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ABSTRACT

Issues of nutrient management were studied in ten countries of the Danube Basin in the frame of the Danube Environment Programme. Comprehensive data collection covered socio-economic and natural factors influencing nutrient balances, water quality of the Danube and its tributaries, and major features of wastewater management for municipalities. The innovative methodology of materials accounting was applied to develop nutrient balances for the countries involved and the Danube Basin, and to get insight on causes, temporal changes of stocks and early recognition. The approach was cross-checked against loads estimated from ambient water quality observations. Main dilemmas of water quality management (local problems, and the regional eutrophication of the Danube Delta and the Black Sea) were identified and options of load reductions were evaluated. Agriculture pollution of mostly non-point source origin was found as the key of developing an integrated emission reduction policy for the Basin. Municipal wastewater management strategies were studied in detail. Recommendations were given on strategy development, monitoring, research and improved international cooperation in the Danube/Black Sea Basin.

KEYWORDS

Black Sea; Danube; eutrophication; large river basin management; materials accounting; nutrients; wastewater management.

INTRODUCTION

The Danube Basin covers 817 000 km^2 and includes twelve countries (small portions of five other countries also belong to the watershed) where more than 85 million people live. Water quality of the main river due to its high dilution capacity did not require urgent actions like many industrially heavily contaminated rivers in Europe and international cooperation remained limited for several decades. It was recognized only at the beginning of the nineties (when the political atmosphere has also changed in the region) that long term environmental objectives of the Basin and the Black Sea call for improved, basin wide collaboration on various fields. The Danube Environmental Programme was launched by the EU and GEF (see Botterweg and Rodda, 1999). The present study formed a component of this undertaking.

High nutrient loads and their consequences are recognised as one of the most severe problems of the river Danube catchment area, the Danube Delta and the Black Sea. The quality of the main Danube is acceptable, but nutrient levels are high and signs of eutrophication are apparent. Oxygen depletion and high ammonia levels often occur in smaller tributaries and nitrate contamination of groundwater is also a major water quality issue.

The complex ecosystem of the Danube Delta has deteriorated dramatically over the past few decades due to high nutrient loads, and hydrologic and morphologic changes. A major part of the Black Sea got critically eutrophic (see e.g. Mee, 1992). Increased algal blooms, a massive loss of water macrophytes, widespread reduction in dissolved oxygen concentrations, changes in the food-chain etc. are consequences of the undesirable alterations. During past decades inorganic nutrient concentrations along the Romanian coast have increased by an order of magnitude (Vadineanu *et al.*, 1992). Loads carried by the Danube have showed similar changes (EU/AR/203/91): total nitrogen (TN) load increased from 50 kt/y in 1960 to close to 500 kt/y in 1988, while total phosporus (TP) load exhibited roughly a five times growth from about 14 kt/y in 1960 (consequently the N:P ratio was lifted). The 1989-1992 period showed peculiar alterations: significant fluctuations in the TN load and a gradual decrease in TP load (down to 18 kt/y) leading to further increase in the N:P ratio. These latter changes are not well understood and monitoring problems can be also suspected. Both, phosphorus and nitrogen seem to be important, but it is not yet clear at what extent emissions have to be reduced.

In the catchment, local water quality problems and eutrophication in a regional scale (the Danube Delta and Black Sea) should be handled simultaneously, a difficult and somewhat conflicting issue which calls for a basin wide nutrient emission reduction programme. The broad objective of the present study covering ten riparian countries (Germany, Austria, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, Moldavia and Ukraine) was to analyze some of the related strategic issues. Specific ojectives included (i) to develop a methodology and technology transfer in the riparian countries to improve the understanding on the behavior of nutrients and management issues related; (ii) to provide nutrient balances for the countries involved and the Danube Basin (for 1988 and 1992 to study the impact of economic transition); and (iii) to identify main problems for water quality management and to evaluate options for load reductions (with emphasis on efficient strategies for wastewater management).

In order to meet the above objectives a comprehensive data collection was performed on (a) socio-economic and natural factors influencing nutrient balances in the anthroposphere and environment, (b) water quality of the Danube and its tributaries for the two historical years and (c) major features of wastewater management (national levels and municipalities larger than 10 000 inhabitants were considered). Details of the study can be found in the Final Report of the study (EU/AR/102A/91, 1997) and numeroues technical reports associated. Here, we address only the most important strategic and methodological issues.

METHODOLOGY: MATERIALS ACCOUNTING

In order to tackle nutrient management in the Danube Basin, a number of questions have to be answered. What exactly are the problems and their causes? What is the development of the situation over time and how to achieve early recognition? What are the most efficient, preventive means to solve these problems?

The traditional methodology considers water, only and is based on the development of an inventory of nutrient related activities in the watershed and estimates of losses to water (e.g. on the basis of unit areal loads, head specific load values etc.). The emission estimates can be refined on the basis of longitudinal changes of loads derived from ambient water quality observations (called net immission loads). The method is descriptive: it can lead to emission estimates, but it is not suited to answer the above questions.

To address strategic issues, an innovative, multidisciplinary approach called materials accounting (see Baccini and Brunner, 1991, Lampert and Brunner, 1999) has been applied which was often used for the study of industrial plants. It focuses on the relevant sub-systems (called processes), and corresponding flows and stocks of materials within a defined region consisting of the environment (water, air, soil etc.) and the anthroposphere (or "society") with various productions (industry, agriculture, trade etc.), consumptions etc. driven by man's biological and cultural needs. In our case a region can be a sub-basin, a country or the Danube Basin. The application of the methodology on such large scales is not yet known.

The method is based on the balance principle applied to elements of the environment and anthroposphere alike for all the goods (fertiliser, meat etc.) and chemicals (e.g. nitrogen or nitrate): inputs and outputs of each nutrient related process must be balanced. Material flows and stocks are estimated on the basis of measurements, literature, regional statistical data, expert advises etc. in various steps (assessment of the quantity and concentrations of goods, transformation coefficients such as N fixation or denitrification, and calculation of fluxes and the stored material). For example "agriculture" inputs include manure, mineral fertilizer and sewage sludge applied, atmospheric deposition, N fixation etc.; outputs are among others harvested crops, percolation, gaseous losses, erosion, animal products and feed exported etc.; and finally stocks of goods are differently utilized agricultural soils, animal biomass, stored manure etc. The flow of goods is driven by human activities, environmental conditions or by both of them.

Due to constraints in knowledge, data availability, uncertainties of various origins (Buzás, 1999) and other factors, the rigid requirement of closing all the balances is rarely fulfilled. Thus, the method has to be combined with and cross-checked against other approaches such as ambient water quality based loads as for the traditional method. The significant gain of the new approach is to get insight on causes, temporal changes of stocks and early recognition. The method also allows to identify the main primary sources of emissions and may lower the amount of observations needed: monitoring by materials accounting techniques often yields more comprehensive information with less cost than direct monitoring (e.g. by soil and sludge sampling programs). In short, materials accounting is a valuable tool for the development and implementation of preventive strategies.

If a huge system such as the Danube Basin is investigated by a large international team - a unique effort, the use of a common methodology is necessary. Every "partner" defines the system boundaries in space (a country) and time, as well as the processes, flows of goods and stocks within the system. The data can now be compared more easily, and differences in the base figures become visible and can be discussed for their plausibility. It is the use of a uniform methodology and common language which eventually allows to draw general conclusions about nutrient flows in the total basin, and facilitates future understanding and the implementation of nutrient management measures.

RESULTS OF MATERIALS ACCOUNTING

The results of materials accounting allow to draw conclusions on priorities to control nutrients in the Danube Basin (see Fig. 1). Agriculture is the main source of nutrient input into the River Danube. Erosion is the main pathway to surface waters for both P and N. The direct inputs of liquid manure from agriculture are high (about 12% of the N load and about 20% of the total P load). The second largest source of nutrients is private households (about 20% of the total N and P load). The fraction originating from industry amounts to approximately 10% each for N and P. Regarding the pathways of nutrient inputs into the River Danube, materials accounting yielded the following results: for surface waters, the main nitrogen load (35%) is due to exfiltration of groundwater. Erosion/runoff, direct input and municipal sewage treatment plants each contribute about 20–25% of the total load.

Almost half of the nutrient input originates from Romania, while Germany, Austria and Hungary jointly contribute about one-third of the nutrient load to surface waters of the Danube's catchment area. Between 1988 and 1992 the nutrient input into the Danube dropped by about 15%. Loss of N by denitrification (and sedimentation) amounted in both years to about 20% of the total N load; for total P about 35% and 50% was retained by sedimentation in 1988 and 1992, respectively.

The results of the two years (1988 and 1992) show, that the consumption, and subsequently the emissions of most nutrient flows decreased during the economic transition in the Central and Easter European (CEE) countries. This decrease is also reflected in improved quality of receiving waters. The material balances of different countries deviate due to natural and man-made differences, as well as due to assumptions taken by the partners. The ranges of specific values are relatively narrow for nitrogen and wider for phosphorus. This shows on one the hand the need for further refinement of the balances; on the other hand, this suggests to use an individual approach for the design of nutrient management strategies for each country.

Out of the total input, about 60% of N and 40% of P stemmed from diffuse sources on the Danube level which shows a similar pattern than for many river basins in Europe.

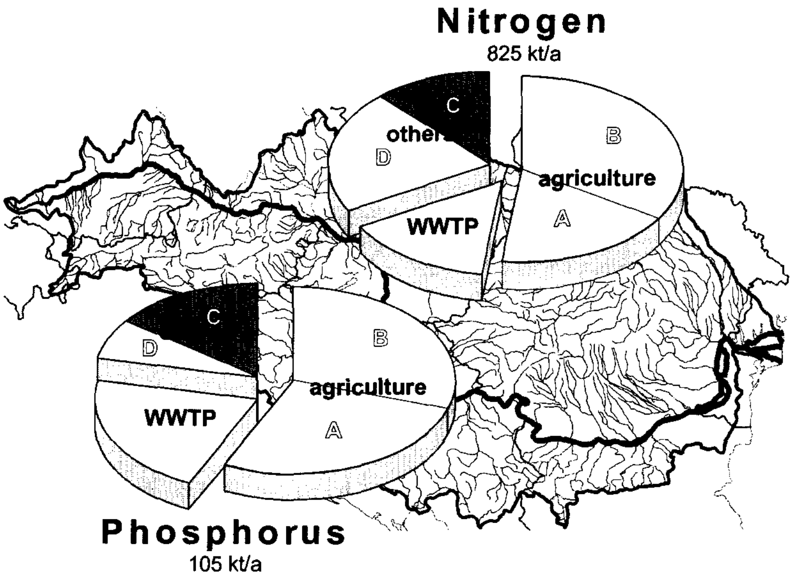

Figure 1. Sources of nutrients in the catchment area of the Danube (1992). Notation: A - direct and indirect inputs (i.e., via treatment plants) of animal waste products; B - erosion and leaching of nutrients agricultural fields; WWTP - waste water treatment plant; C - direct inflow from private households and industry; D - diffuse inputs from forestry (erosion and percolation)

SHORTCOMINGS OF WATER QUALITY MONITORING

Spatial mass balance set for a certain region of a river system is a "section" of a full materials accounting for the same region which - as said - can be employed for the purpose of cross-checking if detailed and reliable flow and water quality data are avaialable. The Danube Basin raises lots of difficulties in this respect.

The total length of the Danube monitored is about 2 500 km (it is about 35 000 km for the entire river system), while in total, sampling sites are close to 850. Annual sampling frequency varies between 6 and 52 depending on country and the importance of the site, however due to budgetary problems in many countries the frequency is irregular and smaller than designed - e.g. (3-4)/year in Bulgaria. Some of the crucial parameters of nutrient balancing such as TN and TP are not (or only rarely) measured. Sampling and analytical methods are different thus hampering comparability. By now, data about nutrient concentrations during high flow conditions are at best exceptions. Difficulties of mass balance evaluation can also emerge from the lack of flow data for several sampling locations.

Due to the above reasons, no strict water quality evaluation is possible at present for the Danube and its sub-basins (to which the lack of a unified classification system also contributes). The longitudinal profiles of inorganic N and P for the main Danube show a characteristic difference: while N concentration decreases downstream, the P content increases homogeneously. Significant difference was also found in the temporal changes. Between the two reference years, 1988 and 1992 the concentration of P was halved along the total length of the river. In contrast the N concentration remained nearly on the same level.

On the basis of statistical analyses of monitored data performed (for details see Clement and Buzás, 1999) mass fluxes of the cross sections of the Danube upstream and downstream at the first order tributary mouths are mostly unbalanced. Reasons include the low sampling frequency and the small order of magnitudes of loads of tributaries in comparison to high loads carried by the Danube.

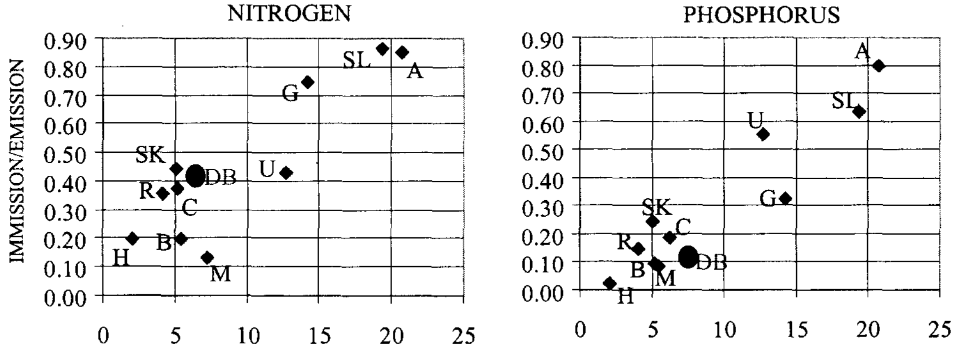

Figure 2. Net immission load/emission load vs specific surface runoff in different countries (1992).
A - Austria, B - Bulgaria, C - Czech Republic, G - Germany, H - Hungary, M - Moldavia, R - Romania, SK - Slovakia, SL - Slovenia, U - Ukraine, DB - Basin average.

The ratio of nutrient load increase within a country and the actual emission of the same country (which characterizes transfer and retention in receiving waters) varies in a broad range, reflecting primarily surface runoff conditions (see Fig. 2). The highest retention was found in Hungary with the lowest specific average surface runoff. The lowest retention was found in Austria, Slovenia and Germany where surface runoff is the highest. Since the error of both, emission and immission load estimates are high, care should be taken to draw too specific conclusions on emissions and impacts of individual countries or subwatersheds. The results of Fig. 2 are in harmony with Behrendt (1996) who found that there is a strong dependency of retention and loss processes on the specific runoff and the mean concentration. The smaller the specific runoff the larger is the difference between emission estimates and load increases.

On the basis of data available, the TN and TP loads reaching the Black Sea can be estimated as 447 kt and 46 kt in 1988, and 345 kt and 25 kt in 1992. These immission loads are about 40% and 25% of the TN and TP emission estimates obtained from the method of materials accounting which clearly demonstrates the significant role of "self purification", retention and losses in the river system (sedimentation, denitrification etc.).

ISSUES OF EMISSION REDUCTION STRATEGIES

The future question is how will the changing economy, the growing living standard as well as the increasing per capita turnover in the CEE countries affect water quality in the Danube River Basin? Crucial for the turn of events will be the consumption behaviour, the type of agriculture also depending on the overall European trends and whether the emission standards issued for industry, households and urban wastewater can be met in the future.

According the scenarios investigated, the decrease in the total flow of nutrients in the Danube Basin measured in 1992 will be temporary, only, and will be followed by a future increase. Even if best available agricultural techniques are considered, future nutrient management will accumulate P in soils. This means an increasing long-term phosphorus stock determining erosion/runoff of P in the future (which contributes already today one third to the surface water load).

The development of a basin wide integrated strategy is of crucial importance. Due to its significance, agriculture (and associated non-point source control) is the key of the future. It is unclear how a related policy can be developed and implemented: ongoing economic transitions and not too systematic changes of the sector in CEE countries, many country specific conditions, EU trends, the complex international setting, difficulties of diffuse pollution abatement all cause serious dilemmas.

N and P loads from municipal and industrial point sources amount to only about 25% of the total nitrogen and 33% of the total phosphorus emissions in the investigated Danube catchment area. Target loads of the

Black Sea are not yet known, but significant reductions will be needed. Our study has shown that by introducing high level of treatment for all settlements larger than 10 000 inhabitants, TN and TP emissions can only be reduced by about 16% and 20% (an additional 10% TP reduction could be achieved by introducing P free detergents) and costs are well defined. The development of an integrated strategy would require to know what is the efficiency of the control of agricultural sources, to avoid the abuse of limited financial resources.

From the viewpoint of the Black Sea, the location of pollution reduction in the Danube catchment area depends on retention processes (see Fig. 2) and due to the need to solve also local water quality problems, no easy answer can be given. We can solely state that there is a definite need to develop a Danube Basin emission reduction plan on the basis of which riparian countries should agree on national actions, together with their scheduling (like it was done for the control of acidification under the umbrella of EU).

Like agriculture, industrial and trade effluents also have a broader European dimension. The concern is the possible distortion of competitiveness between similar industrial production sites within the continent, depending on different national pollution permit standards. If only an ambient standard principle is adopted, the pollution discharges e.g. to river Danube could be much higher than to all other receiving waters in the catchment area. This could result in a strong concentration of industry and trade along the River Danube which is in conflict with those countries already having a strong precautionary (emission standard) principle based legislation. One of the problems is that the European Draft Framework Directive for water quality management does not state clearly whether for N and P the precautionary principle has to be adopted or not. Eventually the question is whether - with all the consequences - the Danube/Black Sea Basin should be declared a "sensitive" area and for what discharges.

The present study dealt with point source control and wastewater management quite in detail. Results can be found in Zessner *et al.* (1998 and 1999). Here we summarise only a few strategic findings.

(i) Municipal wastewater management is far from being satisfactory and needs development. In the investigated CEE countries only about 50% of the population of 58 million inhabitants is connected to sewer systems. About 20% of wastewaters is directly discharged into receiving waters, 10% is treated only mechanically, 52% is processed by high rate biological treatment and about 18% receives higher level of treatment (nitrification with, or without nutrient removal). More than 60% of the treatment plants are older than 15 years, many sewer systems have been neglected during the last decades, and need increased repair and maintenance in order to avoid groundwater pollution. Sewage sludge is mainly landfilled which is in contradiction with modern waste management strategies.

(ii) Priority should be given to upgrade treatment to the existing level of sewerage. New sewerage construction is expensive, and is recommended to be postponed unless hygienic reasons and/or drinking water protection require it. New sewer construction will increase the N and P loads discharged to receiving waters and the Black Sea, as long as these are not simultaneously equipped with advanced wastewater treatment. New treatment plants of only three big cities in the basin would reduce emissions of untreated wastewaters by nearly 50%.

(iii) For about half of the population living in settlements with more than 10 000 inhabitants the dilution capacity is so low that biological treatment with nitrification will be required. A plant of reliable nitrification can be designed practically without additional costs for a mean N load removal of about 70% (Kroiss et al.1996). Such plants can be equipped with P-precipitation (80-90% P removal) with little increase in total costs. Cost-efficiency decreases whenever removal rates beyond 70% for nitrogen and about 80% for phosphorus have to be met. It will be possible to decrease P load to the Black Sea within a relative short period of time. However, the design of N and P removal requires extreme care since undesired N/P ratio may have negative impacts.

(iv) Data for direct industrial wastewater dischargers are poor. Industrial problems will have to be solved by an integrated pollution prevention strategy. A strong precautionary concept for the control of hazardous substances should be applied immediately beginning with newly developing industries.

CONCLUSIONS

From the study performed we draw conclusions as follows.

(i) The method of materials accounting is an innovative approach to analyse nutrient balances on a large river basin, and to develop preventive management strategies and efficient monitoring programmes.

(ii) The key of handling the nutrient problem of the Danube/Black Sea Basin is agriculture representing about 50% of nutrient sources in the Danube Basin (mostly of diffuse nature). The development of a basin wide integrated strategy is of crucial importance, which requires to know the efficiency of the control of agricultural sources in comparison to that of the point sources. Point source abatement can realistically contribute to only about 20% of emission reductions. An emission reduction programme of all the riparian countries should be agreed upon which includes locations of actions, scheduling and costs. Its preparation necessitates to set local water quality goals and standards for surface waters, and load targets for the Black Sea. The latter raises a number of scientific issues.

(iii) Priority should be given to upgrade treatment to the existing level of sewerage. New sewerage construction is recommended to be postponed as long as economy does not allow it (unless hygienic reasons or drinking water protection require it). New sewer construction should be associated with advanced wastewater treatment. New treatment plants of only three big cities in the Basin would reduce emissions of untreated wastewaters by nearly 50%.

(iv) Sampling, analytical, classification and evaluation methods should be standardised in the Danube Basin. It is recommended to put a much stronger focus on monitoring under high flow conditions at important sites (large tributaries, high emission zones, country borders and the final discharge points into the Black Sea). It is also proposed to establish national nutrient balances which are adjusted periodically. Systematic studies are needed to explore the relation between emissions and ambient water quality and to develop comprehensive action plans.

(v) International efforts on the Danube Basin and the Black Sea should be better integrated in the future. Disseminations of results achieved in the frame of the Danube Environmental Programme and follow up activities to transfer knowledges to solve important practical problems in the region are crucial.

ACKNOWLEDGEMENTS

We are indebted to many of our colleagues from our departments and from participating riparian countries for their valuable contribution in coordination, data collection and analyses, scenario development and other activities. We express particular thanks to A. Bartosova, D. Berankova, K. Buzás, A. Clement, D. Drumea, R. Fenz, J. Kapanina, M. Knolmár, C. Lampert, V. Mosanu, C. Postolache, M. Ros, G. Sukhorukov, N. Tzankov, A. Vadineanu, I. Varlev, J. Zagorc-Koncan and M. Zessner. The funding of the research by the PHARE programme is highly appreciated.

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