Tentative nitrogen budgets of lower Krka and upper Savinja river basins in Slovenia

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Abstract

Within a targeted research project aimed at definition and verification of a methodology for the determination of areas, vulnerable to nitrate pollution, and of the respective remedial measures according to the EU nitrate directive 91/676/EEC, tentative nitrogen budgets for two characteristic river basins were elaborated in Slovenia.

In the case of lower Krka river, it was found that the total nitrogen concentration load seems to be discharge independent, i.e., high discharge periods convey correspondingly higher quantities of total nitrogen. This might eventually be a general case for the lowland karst streams. Further, it was found that for the lower Krka river basin, the nitrogen budget could be determined precisely enough to fit the precision margins imposed by the Krka river nitrogen inflow at its upstream edge and nitrogen outflow at its downstream edge. But it was found out also, that these precision margins are rather loose due to the relatively high upstream edge nitrogen load of the river, allowing the analysed river basin nitrogen budget to fit easily.

For the upper Savinja river basin it was found that the nitrogen budget can not be determined precisely enough. Several sources of error may have to be chekked: nitrogen import to groundwater from septic tanks and from agriculture, Savinja river basin outflow and nitrogen load at high discharge. Theoretically, discharge related changes in pollution load are connected to the relative importance of point and diffuse pollution sources. Given the structure of the nitrate budget of the upper Savinja river basin, with agriculture being the most important, diffuse pollution sources should prevail. Consequently, high discharge waters should not be less but eventually even more charged. It remains to be checked whether this may be the normal pattern of the alpine streams, since some of them show just the opposite reaction.

We may conclude, that the applied methodology of river basin total nitrogen budget determination has proven to be reliable enough with a good potential to get even more precise. However the river water quality monitoring should have a better discharge coverage especially with respect to high discharge periods. To achieve a better internal regionalisation of the analysed river basins with respect to the nitrate pollution and vulnerability, the existing data structure must be made more appropriate. By now, this can only be achieved on basis of related specific studies and data collection.

The study has also demonstrated, that the population may be a bigger source of total nitrate pollution as readily believed. While this extent is relatively obvious for urban areas, it is less clear for disperse settlement. No data are available which would enable to check the nitrogen reduction efficiency of the existing septic tanks and other equivalent sanitary facilities. So, part of the pollution deriving from disperse settlement is actually being attributed to agriculture.

Introduction

In the European Union is the protection of water resources with respect to the nitrate pollution regulated by the nitrate directive (91/676/EEC). This directive requires a definition of nitrate pollution vulnerable areas, where agricultural activity and use of fertilisers have to be restrained or controlled due to a probable transfer of excessively applied nutritients to groundwater and surface waters. Elevated nitrate water content and observed eutrophycation of surface water bodies are used as primary criteria for the determination of such areas.

According to a European environment status report (EEA, 1995) in 87% of European areas with a developed agricultural activity the groundwater nitrate concentration exceeds 25 mg/l and in 22% of them it exceeds 50 mg/l, actually prescribed as a drinking water acceptance limit. Such areas can unfortunately be found also in Slovenia.

Slovene territory is from a regional hydrologic aspect divided between the Danube Basin and the Mediterranean Basin. On the European Scale these were defined as eutrophic areas. In a search of a policy complying with the Aquis Communotaire, the Slovenian Ministry of Environment and Physical Planning has decided to develop and to verify a methodology for the determination of nitrate pollution vulnerable areas. A determination of a set of measures should enable Slovenia to comply with the EU nitrate directive. A targeted research project, designed to respond to the above goals, was financed jointly by Ministries of Science and Technology and of Environment and Physical Planning of the Slovene Government and carried out by a consortium of Slovene research institutions. Within this paper, the authors try to present the main lines of the applied methodology and its results and draw attention to some of the emerged questions that need to be further researched.

Methodology

On the basis of the water nitrate content data, resulting from the existing Slovene water quality monitoring network, vulnerable areas were determined according to the criteria of the EU nitrate directive (91/676/EEC). It was observed that on most of the Slovene flatland areas, formed of Pleistocene gravel deposits, groundwater nitrate content in 10-50% of cases exceeds the above 50 mg/l nitrate content limit. They should be therefore defined as nitrate pollution vulnerable areas. According to the 50 mg/l nitrate content limit criteria, surface waters in Slovenia can not be defined as

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nitrate pollution vulnerable. With respect to eutrofication, the controlling factor is actually the phosphorus content. This, however, is not a matter of concern of the EU nitrate directive.

In order to understand the nitrogen compounds dynamics within the environment and the effects of relative pollution abatement measures, a methodology of the nitrogen budget determination at a river basin scale was elaborated (DROLC, 1998). Nitrogen compounds dynamics within a river basin was studied by means of a nitrogen material flow analysis. By linking sources, paths and sinks of the individual substances, this method enables within a river basin the identification of the main pollution sources. The results of an analysis of material flows, coupled with the results of surface water quality monitoring, enable a comparison of emission values (pollution sources) with the imission values (experimentally determined actual pollution load within the river). Nitrogen is from point and diffuse sources transferred into surface waters through different paths and transport media (soil, air, water). Due to this, its budget has to include two ecosystems – aquatic and terrigenous.

Human activities (processes), constituting main pollution sources within a region, were grouped according to activity type (population/settlement, industry, agriculture, atmospherical deposition and natural background). Main water bodies (surface waters, groundwater), representing the study subjects, were also defined. By doing this, we can display consequences of individual human activities, process interaction and impacts to the environment. In a river basin nitrogen budget determination we have considered:

❶ activities, emitting nitrogen compounds into waters, and,

❷ emission or transport pathways into environment (direct release of waste water, leakage, erosion, evaporation, atmospheric deposition, …).

As nitrogen pollution sources are either point or diffuse, it is important to determine the main transport pathways with respect to these sources. They are:

❶ point sources - direct releases of waste water, and,

❷ diffuse sources - erosion and diffuse surface flow, soil leaching and percolation to groundwater, evaporation to the atmosphere, diffuse, uncontrolled point releases of waste waters, atmospheric deposition.

The most important processes involving nitrogen compounds are:

❶ nitrification and de-nitrification of nitrogen compounds,

❷ autopurification through reactivation of organic compounds, and,

❸ nitrogen compounds assimilation. Due to the dynamics of these processes can the nitrogen compounds emission to imission ratio serve only as an estimate and rough approximation of the actual state.

In order to determine the budget of nitrogen compounds, human activities were divided into the following processes:

❶ process ”waste waters”, and,

❷ process ”agriculture” with sub-processes ”farm” and ”arable land”. Atmospheric deposition and natural background were integrated into the process ”agriculture”.

Also distinctive constituents of the environment, involving each a multitude of processes, were considered as individual macro-processes, i.e., ”process surface waters”, ”process groundwater”.

Material flow analysis is methodologically based on the data, which, by their origin, fall into the following categories:

❶ experimentally determined values from the analysed region,

❷ values, extrapolated from state to regional level,

❸ values, determined experimentally in a comparable region,

❹ data from literature, and

❺ expert opinions.

Two river basins were selected to test the proposed methodology and to check whether the existing data structure at state and regional level as well as the actual scheme of water quality monitoring allow us to determine and to monitor the existing nitrate and nitrogen loads. Further, they should enable a test of their adequacy of control of the respective pollution abatement measures. The position of these river basins within Slovenia is shown in *Figure 1*.

The lower Krka river basin, situated between the town of Novo Mesto and Krka’s outflow to Sava river, was selected because it is nutritient loaded and therefore urgently needs some effective pollution abatement measures. It has a typical set of human activities (urbanisation, industry, agriculture). Novo Mesto at its upstream edge is a strongly urbanised and industrialised regional centre. Krka river is a typical karst stream of a hilly area, with upper Krka having

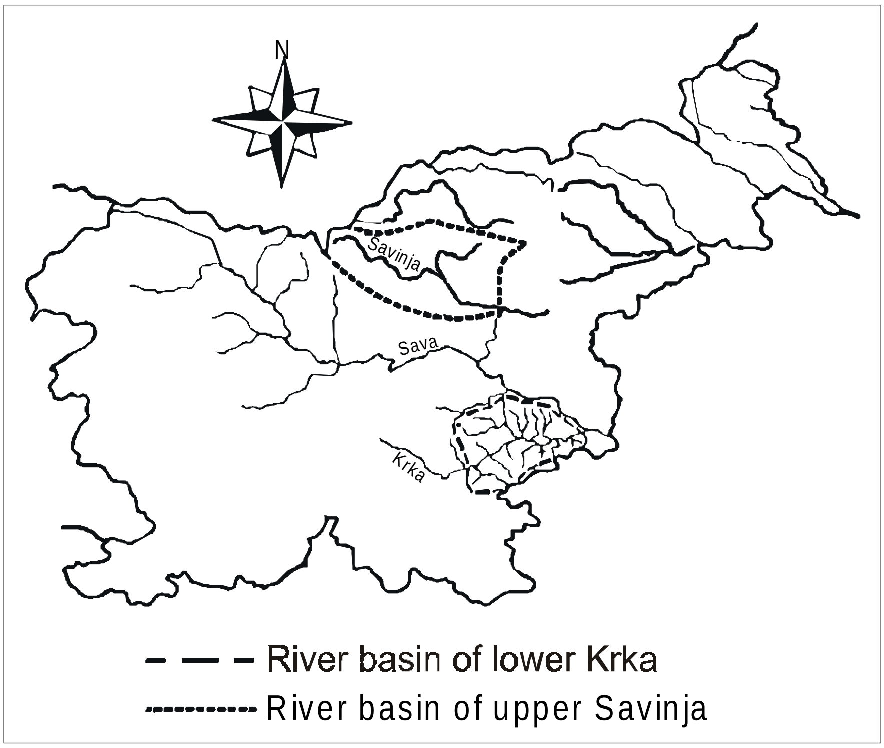

Figure 1: **Situation of lower Krka and upper Savinja river basins**

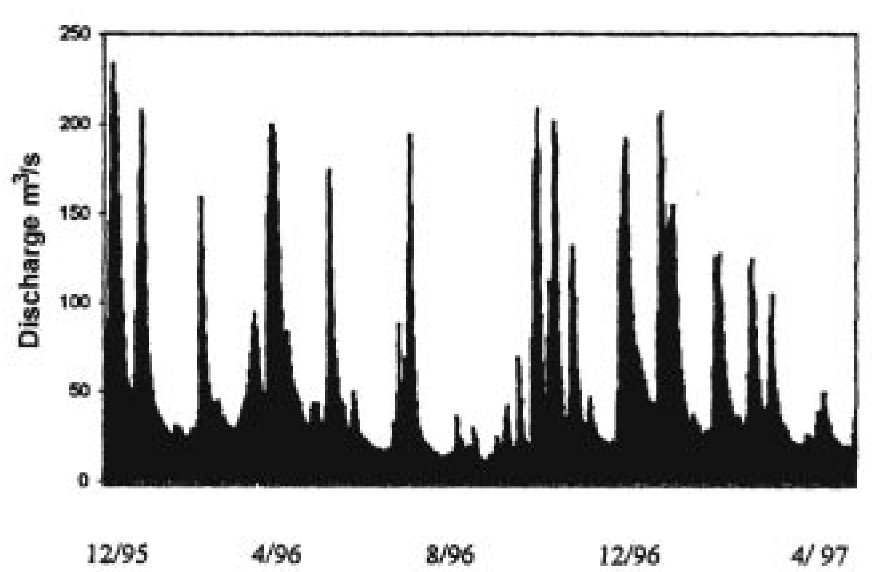

Figure 2: **Krka river discharge at Podboèje (from DROLC, 1998)**

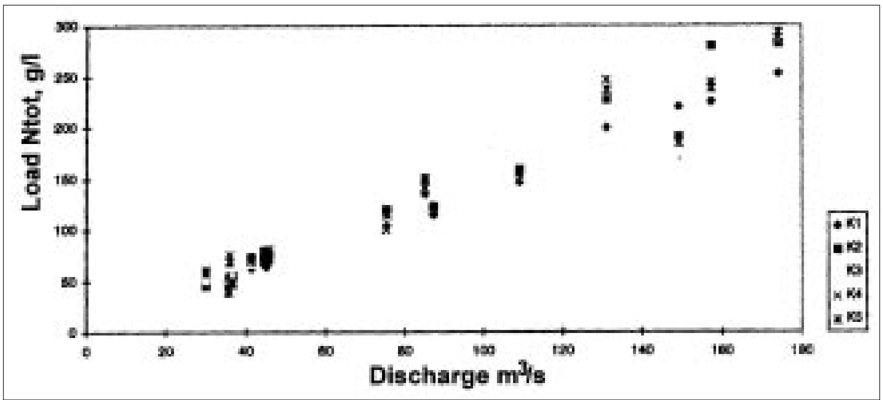

Figure 3: **Nitrogen load versus discharge for river Krka (from DROLC, 1998)**

nearly exclusively carbonate watershed and the corresponding discharge conditions. Environmental conditions in the lower Krka river basin range from hilly to a river plain and from pristine forest to intensively cultivated and urbanised. The method applied is based on the analysis of total nitrogen flows within the river basin and is being often used for nitrogen budget elaboration, cf. Upper Austria (DROLC, 1998). Point and diffuse nitrogen sources are identified for the purpose, as well as the media of nitrogen transport and the transport paths and processes. A river basin is regarded as a single budget entity, with human activities as sub-budget categories. By this, the environmental impacts of various human activities can be assessed as well as interaction and possible nitrate pollution reduction issues. No internal subdivision of a river basin according to its natural conditions, human activities, or pollution loads and other constraints is involved.

The upper Savinja river basin was selected for its variety of environmental conditions ranging from pristine alpine and forested pre-alpine to heavily agriculturally loaded and urbanised river valleys and plains. Alpine and pre-alpine areas are built preponderantly from carbonates. Hilly regions are mostly formed of little pervious Tertiary strata. Valleys and plains are filled with Pleistocene gravel deposits. Savinja river and its tributaries have a strong flooding potential and are typical alpine and pre-alpine streams. Their water quality varies in time and space, ranging from excellent to poor. Pleistocene gravel aquifers in valleys and plains are important drinking water sources and locally heavy nitrate polluted. At least locally, remedial measures against nitrate pollution must be implemented. The same nitrogen budget methodology as for the lower Krka river basin was applied also here. However, due to its complex structure, the upper Savinja river basin was subdivided into sub-basins, where basins of its tributaries and of specific Savinja river sectors were also analysed as individual budget entities. In this way, we have performed a regionalisation of the river basin.

Results

With respect to the nitrogen budget determination, the import of the nitrogen into the basin by the Krka river at the basin's upper or inflow edge and its export by the Krka river at its lower or outflow edge had to be determined to set the basin's boundary conditions. For this, the data on Krka river discharge data and on its water quality from the state's monitoring network were analysed, where 1996 was taken as a reference year. The hydrograph of river Krka at its river basin outlet for the analysed period is displayed on *Figure 2*.

In the case of lower Krka river, it was found that the total nitrogen concentration load seems to be discharge independent, i.e., high discharge periods convey correspondingly higher quantities of total nitrogen. This might eventually be a general case for the lowland karst streams. *Figure 3* presents the obtained relation between nitrogen load and Krka river discharge.

As previously explained, human activities were for the purpose of the lower Krka river basin nitrogen budget determination divided into processes "waste waters" and "agriculture" with sub-processes "farm" and "arable land".

With respect to the "waste waters" process, it was considered that:

❶ the analysed basin has 52.300 inhabitants (yielding 12 g/person/day of N),

❷ 17.400 of these are connected to the wastewater treatment plant,

❸ this plant receives 90% of nitrogen input from population and 10% from industry,

❹ nitrogen content removal efficiency of the wastewater treatment plant is 36%,

❺ Novo Mesto sewage system loss to groundwater is 19%,

❻ of 34.800 inhabitants using septic tanks, 3.500 transfer sewage to wastewater treatment plant, 300 release sewage directly to surface flow and the rest let their septic tanks leak,

❼ 60% of the nitrogen that leaks from septic tanks reaches groundwater,

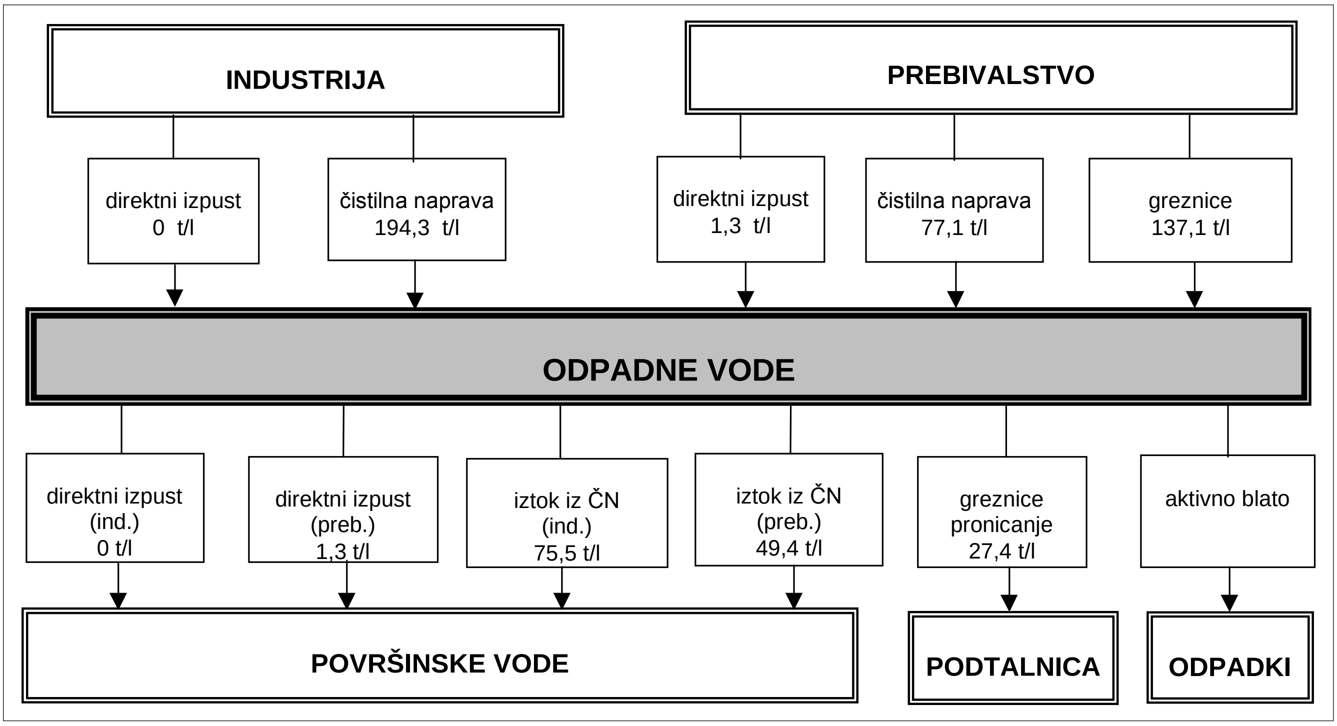

Figure 4: **Process "waste water" for the lower Krka river basin**

❽ nitrogen content removal efficiency of the industrial wastewater treatment plant is 61%. *Figure 4* shows this process.

With respect to the process "agriculture" sub-processes "farm" and "arable land" have to be considered separately. According to statistical data, the river basin surface consists of 34% of arable land, 14% of non-arable land, 46% of forests and 6% of areas without vegetation. According to the same data, its farms breed 286 horses, 17.735 cattle, 21.188 pigs, 991 sheep and 333.562 chicken. The nitrogen application via fertilisers and animal manure to the arable land is considered to be at the mean Slovene level. Atmospheric deposition is determined on the basis of data from Novo Mesto monitoring station. Atmospheric nitrogen fixation is taken 40 Kg N/ha/year on basis of the crop production structure. Within the sub-process "farm" is nitrogen transferred in fertilisers and animal manure from "farm" to the "arable land", in gas losses from "farm" to the atmosphere and in part of liquid manure from "farm" to surface waters. Within this frame is, 15% of all nitrogen produced at the farm released through gas losses to the atmosphere and 1% of all animal manure produced at the farm released as liquid manure to surface waters. *Figure 5* shows this sub-processes.

Results of the above processes and sub-processes and of the nitrogen import and export can be summarised into the annual nitrogen budget of the lower Krka river basin for the year 1996, displayed in the *Figure 6*.

From the above, it can be concluded that the nitrogen input from "surface waters inflow", "waste waters", "groundwater", "agriculture" and "atmospheric deposition" amounts in the case of the lower Krka river basin in year 1996 to 3.438,5 tons of N/annum. All the nitrogen emitted within the lower Krka river basin amounts to 496.8 tons of N/annum. Data on surface waters outflow show for the same period an export of 3.207,8 tons of N/annum. With Krka river's annual discharge determination error being 5% (which is a fairly low value in standard engineering practice) and no nitrogen water load determination error occurring, the error margin for lower Krka river basin's nitrogen budget is of the order of 300 tons of N/annum. The observed difference within the nitrogen export and import values is 230 tons of N/annum. We may conclude that the budget could be determined precisely enough to fit the precision margins imposed by the Krka river nitrogen inflow at its upstream edge and outflow at its downstream edge. But it was found out also, that these precision margins are rather loose due to the relatively high upstream edge nitrogen load of the river, allowing the analysed river basin nitrogen budget to fit easily.

For the upper Savinja river basin the upstream edge inflow is nil and only the downstream edge outflow is to be considered. The already known material flow analysis was carried out, based on the data specific to the Upper Savinja river basin. We summarise here only the annual nitrogen budget of the upper Savinja river basin for the year 1998, as issued from all the analysed processes and sub-processes and from the nitrogen export at the river basin's outlet. The results are presented on *Figure 7*.

From the above, it can be concluded that the nitrogen input from "waste waters", "groundwater", "agriculture" and "atmospheric deposition" amounts in the case of the upper Savinja river basin in year 1998 to 3.000,6 tons of N/annum. All this nitrogen is emitted within the river basin, with agriculture (annual input of 2.414,6 tons of N/annum) being by far the strongest nitrogen source and groundwater (annual transfer of 2.665,2 tons of N/annum) its strongest vehicle. Data on surface waters outflow show for the same period an export of 2.636,9 tons of N/annum. Similarly, with Savinja river's annual discharge determination error being 5% at one measuring point only and no nitrogen water load determination error occurring, the error mar-

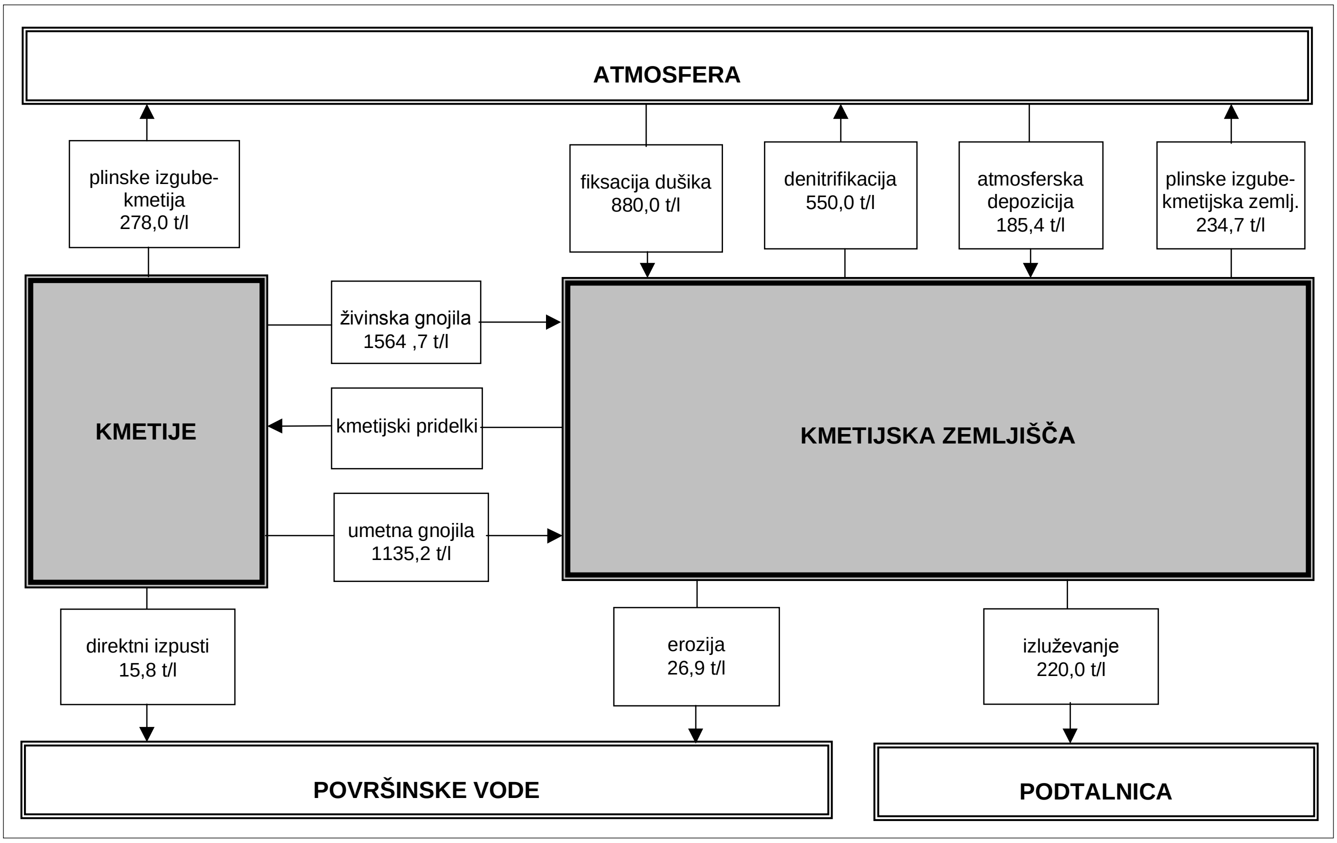

Figure 5: **Process "agriculture" for the lower Krka river basin**

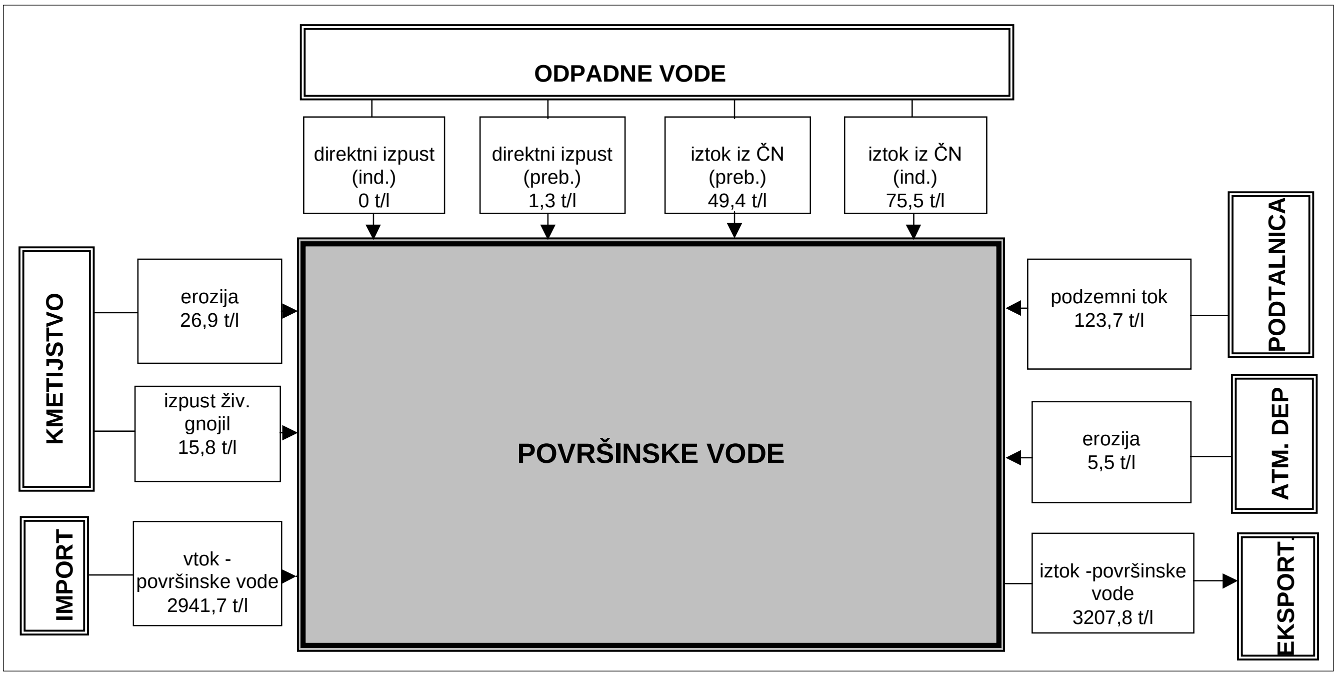

Figure 6: **Nitrogen budget of the lower Krka river basin for the year 1996**

gin for upper Savinja river basin's nitrogen budget is of the order of 130 tons of N/annum. The observed difference within the nitrogen export and import values is close to 364 tons of N/annum and is well above the desirable error margin. We may conclude that the budget could not be determined precisely enough to fit the precision margins imposed by the Savinja river nitrogen outflow at its downstream edge.

No nitrogen import from inflowing surface streams exists in the upper Savinja river basin and we expected to be able to test the method of material flow analysis more precisely as in the case of the lower Krka river basin. Observed nitrogen budget error shows that this is not the case. Several sources of error may have to be checked:

❶ nitrogen import to groundwater from septic tanks (maybe overestimated);

❷ import of nitrogen from agriculture (may also be overestimated),

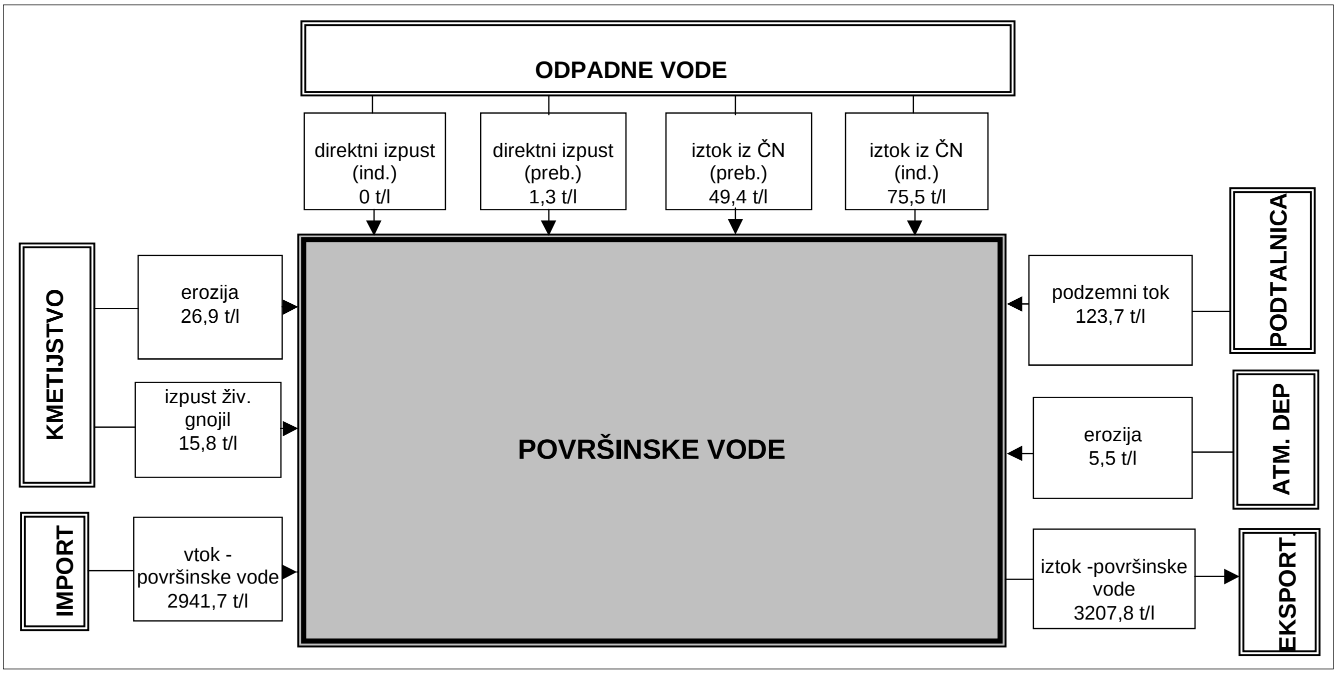

Figure 7: **Nitrogen budget of the upper Savinja river basin for the year 1998**

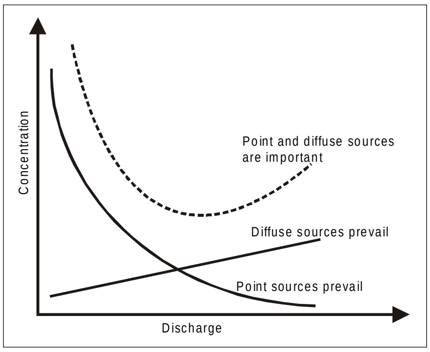

Figure 8: **Load to discharge relation for surface streams (from DROLC, 1998)**

❸ Savinja river basin outflow (it may be higher);

❹ nitrogen load at high river discharge (it may be higher).

Theoretically, as shown by *Figure 8*, discharge related changes in pollution load are connected to the relative importance of point and diffuse pollution sources. Given the structure of the nitrate budget of the upper Savinja river basin, with agriculture being the most important, diffuse pollution sources should prevail. Consequently, high discharge waters should not be less but eventually even more charged. It remains to be checked whether this may be the normal pattern of the alpine streams.

Conclusion

We may conclude, that the applied methodology of river basin total nitrogen budget determination has proven to be reliable enough with a good potential to get even more precise. However the river water quality monitoring should have a better discharge coverage especially with respect to high discharge periods. To achieve a better internal regionalisation of the analysed river basins with respect to the nitrate pollution and vulnerability, the existing data structure must be made more appropriate. By now, this can only be achieved on basis of related specific studies and data collection.

The study has also demonstrated, that the population may in some cases be a bigger source of total nitrate pollution as readily believed. While this extent is relatively obvious for urban areas, it is less clear for disperse settlement. No data are available which would enable to check the nitrate reduction efficiency of the existing septic tanks and other equivalent sanitary facilities. So, part of the pollution deriving from disperse settlement is actually being attributed to agriculture.

Acknowledgement

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