River basin water nitrate quality management with respect to the existing data structures

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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 nitrate budgets for two characteristic river basins were elaborated in Slovenia. River basin of lower Krka between the town of Novo Mesto and its outflow to Sava river were selected, as they are known for being high in nutrients. The river basin of Savinja 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. A tentative of regionalisation by means of GIS registered data was attempted in Savinja river basin. Data on natural conditions and land use, time and space related groundwater and surface stream discharge and nitrate pollution data and regionalised statistical data on human activities (settlement, cattle density and crop or industrial production) were used. The applied methodology of river basin total nitrate budget determination has proven reliable enough with a potential to get even more precise.
1 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 nutrients to groundwater and surface waters. Elevated nitrate water content and observed eutrophication of surface water bodies are used as primary criteria for the determination of such areas. Here this methodology was further developed.

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

2 Methodology

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 [1] [2]. 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 emission 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 (settlement/urbanisation, industry, agriculture, atmospheric 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: 1) activities, emitting nitrogen compounds into waters, and, 2) emission or transport pathways into environment (direct release of waste water, leakage, erosion, evaporation, atmospheric deposition, etc.).
As nitrogen pollution sources are either point or diffuse, it is important to determine main transport pathways with respect to these sources. They are: 1) point sources - direct releases of waste water, and, 2) 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: 1) nitrification and de-nitrification of nitrogen compounds, 2) autopurification through reactivation of organic compounds, and, 3) 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: 1) process “waste waters” with sub-processes “settlement/urbanisation”, “industry” and “industrial farming”, and, 2) process “agriculture” with sub-processes “farm”, “arable land”, 3) process “forest”. Atmospheric deposition and natural background were integrated into the process “agriculture”. Sub-process “industrial farming” must be also included into the process “agriculture” and simultaneously excluded from the process “waste waters”, if nitrogen producing human activities rather that nitrogen compounds transforming and transporting processes are being considered and summarised at a river basin scale.

Distinctive constituents of the environment, each involving a multitude of processes, were considered as individual macro-processes, i.e., “process surface waters”, “process groundwater”. At a river basin scale, “process groundwater” can be seen just as an intermediate transport vehicle, transferring pollutants from their source to surface waters as a terminal receptor, and not presented separately. However, given the importance of major ground water bodies for public water supply and the necessity of their protection, separate nitrogen budgets, have to be elaborated for these groundwater bodies. In an ideal case shall the applied methodology, the existing data structure and the applied model enable an integration of these separate budgets into that of the river basin.

Material flow analysis is methodologically based on the data, which, by their origin, fall into the following categories: 1) experimentally determined values from the analysed region, 2) values, extrapolated from state to regional level, 3) values, determined experimentally in a comparable region, 4) data from literature, and 5) expert opinions.

### 3 Required data structure

Due to the lack of space, we present here as an example the required data structure for the processes “waste water”, sub-process “settlement/urbanisation”, “agriculture” and “surface water”.

3.1 Process “waste water”

3.1.1 Sub-process “settlement/urbanisation”

Inflow into the system requires to be supported by the following data for the appropriate description of the process: 1) Urban and communal waste water: 1.1) Number of inhabitants connected to communal sewage systems, 1.2) Number of inhabitants using septic tanks.

Outflow from the system requires to be supported by the following data for the appropriate description of the process: 1) Urban and communal wastewater: 1.1) Number of inhabitants connected to urban sewage systems discharging directly to surface waters; 1.2) Number of inhabitants connected to urban sewage systems connected to wastewater plants; 1.3) Urban sewage system losses; 1.4) Efficiency of communal wastewater treatment plants with respect to nitrogen removal; 1.5) Number of inhabitants treating septic tanks sewage in communal wastewater treatment plants; 1.6) Number of inhabitants with septic tanks equipped with local sewage treatment facilities; 1.7) Number of inhabitants releasing their septic tanks sewage directly into surface waters; 1.8) Number of inhabitants with their septic tank sewage leaking into groundwater; 1.9) Active mud

Nitrogen production resulting from population is evaluated on the basis of daily nitrogen production rate of humans, being 12 g of N per day per person [2]. Nitrogen emission from septic tanks to the environment and groundwater or surface streams has to be evaluated from data on septic tanks efficiency. Septic tanks may greatly differ in their construction and efficiency. In best cases their annual nitrogen output is estimated to the order of 20% of the input value (references). However, studies of actual field conditions demonstrate a much lesser efficiency (references), with annual nitrogen output exceeding 60% of the input value. No adequate studies in Slovenia exist. Geologic, morfologic and soil conditions greatly influence this value. If data on population (i.e., number, density, settlement distribution) are not pure statistical but geo-referenced or GIS data, these differences can be taken into account.

Active mud, containing nitrogen from wastewater is a wastewater treatment plants waste, deposited on communal waste deposits and thus removed from water circle. In some cases, however, it may be used as arable land fertiliser and constitutes part of its nitrogen budget.

3.2 Process “agriculture”

Information on land use distribution within a river basin is one of the basic data needed to assess the impact of agriculture on nitrogen balance of that basin. It can be delivered as pure statistical data. However, given the ultimate aims of water quality management of a river basin, it is desirable that these data are provided as geo-referenced or GIS data. According to its use, the land of a river basin can be divided into the following categories: 1) Arable land: 1.1) Laboured land (fields, long-term plantations, meadows and grasslands); 1.2) Non-laboured land (pastures, marshes, fish ponds); 2) Forest, 3) Non-fertile land (high alpine, urbanised, rivers and lakes).
Process “agriculture” is taking place on farms and on arable land. Due to the nature of its nitrogen pollution of underground and surface waters it is subdivided into two (or three - see chapter on methodology) sub-processes. Sub-process “farm” constitutes a point pollution source and sub-process “arable land” a diffuse pollution source (eventually, sub-process “industrial farming” can also be added).

### 3.3 Process “surface waters”

Process-wise, inflow into the system can be deduced from outflows of the following two “processes” and by the following additional data on the external nitrogen import to the system: 1) Outflow from the process “waste water”; 2) Outflow from the process “groundwater”; 3) Nitrogen import at the upstream river basin’s border: 3.1) In-flowing river discharge at the upstream river basin’s border; 3.2) Discharge related nitrogen load of the in-flowing river water.

Origin-wise, nitrogen inflow to the system can be elaborated from outflows of the following human activities or “processes” and by the following additional data on the external nitrogen import to the system: 1) Outflow from the process “settlement/urbanisation”; 2) Outflow from the process “industry”; 3) Outflow from the system “agriculture” with sub-process “industrial farming” included; 4) Nitrogen import at the upstream river basin’s border: 4.1) In-flowing river discharge at the upstream river basin’s border; 4.2) Discharge related nitrogen load of the in-flowing river water.

For an appropriate description of the process, outflow from the system must be supported by the following data on the nitrogen export from the system: 1) Nitrogen export at the downstream river basin’s border: 1.1) Out-flowing river discharge at the downstream river basin’s border; 1.2) Discharge related nitrogen load of the out-flowing river water.

### 4 Method verification

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. They should enable a test of their adequacy of control of the respective pollution abatement measures. Their position within Slovenia is shown in Figure 1.

To economise space, we can present here only the Savinja river basin case. It 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 Savinja river basin upstream of Tremerje discharge and water quality gauging station 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.

Figure 1: Situation of river basins of lower Krka and of Savinja upstream of Tremerje

5 Data availability

For Slovenia, the analysis performed on both river basins allows the following conclusions on the existing availability of data, required for nitrogen budget evaluation and for an eventual subsequent river basin water quality management:

Data on sewage systems, treatment plants and number of septic tanks discharged to treatment plants are available through local authorities. No data on septic tank efficiency are available. Data on population can be obtained at communal level. They cannot be geo-referenced at the level of individual dwellings and used for GIS application for geo-referencing the septic tanks leakage. Data on industry and industrial farming are available through local authorities.

Data on animal breeding (animal types and their number) are available only for relatively large statistical regions. These regions unite groups of communes and do not match well with river basins. No precise geo-referencing of these data is possible. No precise geo-referencing of the use of animal manure is possible. Data on anorganic fertilisers are available only for Slovenia as a whole. Farms and companies with highly productive plantations do not disclose their data. No precise
geo-referencing of the use of fertilisers and animal manure is possible.

Geo-referencing of arable land and forest is possible. A rough geo-referenced estimate based on spatial land types distribution and on spatial animal manure or fertiliser application and their respective (literature reported) interrelated leakage is possible.

Geo-referencing of statistical data on non-fertile land is possible. A rough geo-referenced estimate of high alpine and urbanised land can be obtained by using topographic data. However, urbanised land can not be further structured into gardens or parks and constructed or paved land. No direct data on leaching area available and estimates based on analogies must be applied.

### 6 Results

Savinja river sub-basin upstream of Letuš is shown as an example of the applied approach. This is an alpine watershed, with population living of cattle breeding, extensive agriculture, forestry, tourism and small industry. Following tables give basic statistical data on land use, animal production and human population (SewS: sewage system, WTP: water treatment plants, SewT: sewage or septic tanks).

<table>
<thead>
<tr>
<th>Area\Use</th>
<th>Laboured ha</th>
<th>Non-laboured ha</th>
<th>Forest ha</th>
<th>Rest ha</th>
<th>Total ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savinja above Letuš</td>
<td>3.104</td>
<td>11.370</td>
<td>33.182</td>
<td>5.198</td>
<td>52.855</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area\Animals</th>
<th>Cattle</th>
<th>Pigs</th>
<th>Sheep</th>
<th>Goats</th>
<th>Hens</th>
<th>Rabbits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savinja above Letuš</td>
<td>26.194</td>
<td>11.767</td>
<td>1.075</td>
<td>1.043</td>
<td>262.666</td>
<td>4.424</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area\Population</th>
<th>Total</th>
<th>on SewS</th>
<th>on WTP</th>
<th>on SewT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savinja above Letuš</td>
<td>18.175</td>
<td>4.412</td>
<td>4.412</td>
<td>13.763</td>
</tr>
</tbody>
</table>

In the case of Savinja river basin upstream of Letuš gauging station, an analysis of the process "waste water", based on 1998 census data, resulted in the scheme presented in Figure 2.

In using these data with respect to the process "waste water", it was considered: 1) humans yield 12 g/person/day of N, 2) sewage system loss to groundwater is 20%, 3) nitrogen content removal efficiencies of the wastewater treatment plants are 60%, 4) population using septic tanks releases 1% of its sewage directly to surface flow and the rest to groundwater through leaking septic tanks, 5) 60% of the nitrogen leaking from septic tanks reaches groundwater.

An analysis of the process "agriculture", based on 1998 census data, resulted in the scheme given in Figure 3. In using the data with respect to the process "agriculture" it was considered that: 1) the nitrogen application via fertilisers and animal manure to the arable land is at the mean Slovene level, 2) atmospheric deposition can be assimilated to that of the lower Krka basin, determined at Novo
Mesto monitoring station as 15.6 Kg N/ha/year, 3) atmospheric nitrogen fixation is taken 40 Kg N/ha/year on basis of the crop production structure, 4) nitrogen is in fertilisers and animal manure transferred 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, 5) 15% of all nitrogen produced at the farm is released through gas losses to the atmosphere and 1% within liquid manure to surface waters, 6) nitrogen leakage from arable land to groundwater can be estimated from findings (Cestnik 1986) that in Slovenia 40 Kg N/ha leak annually from fields and 15 Kg N/ha from pastures and meadows. Figure 3 shows this complex process.

Figure 2: Process “waste water” for the Savinja river basin upstream of Letuš

Based on 1998 census data, an analysis of the process “forest” yields scheme, shown in Figure 4. By using the above data and considerations also for the process “forest”, it was further considered that: 1) atmospheric nitrogen fixation of 40 Kg N/ha/year can be applied also for forests (may be questionable, but fortunately does not seem to impact the nitrogen water budget, depending only on leakage), 2) no gas losses to the atmosphere and to the surface waters are present since no manure or fertilisers are applied, 3) nitrogen leakage from forests to groundwater is on the basis of by Cestnik [3] recorded annual leaks of 5-10 Kg N/ha/year taken to be 7 Kg N/ha/year.

We think that also non-fertile or non-arable and non-forested land has to be considered in the nitrogen water budget of a river basin. Based on 1998 land use
census data as previously, an analysis of the process "non-fertile land" resulted in the scheme given in Figure 5.

In our approach to evaluate the nitrogen leakage from non-fertile, or better - non-vegetated land, we have considered that 1% of the total basin's area is covered by surface waters, receiving a direct influx from atmospheric deposition. The rest of the "non-fertile" land, which may be either high alpine, receiving atmospheric nitrogen deposition and atmospheric nitrogen fixation, or urbanised, receiving on green surfaces also some fertilising. As already explained in chapters on the required data structure and data availability, no direct data and non-fertile land structuring were available. We have therefore for such areas assumed a mean leakage of 10 Kg N/ha/year, which may slightly underestimate the output from urbanised land.

![Figure 3: Process “agriculture” for the Savinja river basin upstream of Letuš](image-url)
A river basin’s nitrogen budget for surface waters as its main recipient and outflow vehicle can be obtained on basis of the above considerations and analyses. Within this budget the inputs from main human activities and natural sources can be evaluated and compared. For the Savinja river basin upstream of Letuš, the surface waters nitrogen budget was found to be as displayed on Figure 8.

To control the nitrogen budget estimate with an estimate based on data from river discharge and quality monitoring, the data from river Savinja basin’s outlet gauging station at Letuš were considered. Mean annual discharge in the year 1998 was 20.4 m$^3$/s, with mean annual nitrogen concentration being 0.8345 mg N/l. This yields for 1998 an annual nitrogen export estimate 536.5 tons N/year. It must be noted that nearly all nitrogen is transported as nitrate, with nitrogen from ammonia being close to nil.

\[ \text{N fixation} \quad 1327.3 \text{ t/y} \]
\[ \text{denitrification} \quad 1612.6 \text{ t/y} \]
\[ \text{atmospheric deposition} \quad 517.6 \text{ t/y} \]
\[ \text{gas losses} \quad 0 \text{ t/y} \]

\[ \text{erosion} \quad 0 \text{ t/y} \]
\[ \text{leakage} \quad 232.3 \text{ t/y} \]

**Figure 4: Process “forest” for the Savinja river basin upstream of Letuš**

The estimated nitrogen input exceeds the hydraulically and chemically evaluated nitrogen output at the river basin’s Letuš outlet for 26%. This exceeds the desired 5-10% N mass output gauging error and seems to be quite high. Nitrogen budgets of other sub-basins of the Savinja river basin upstream of Temerje gauging station, show that the method’s sensitivity is within the 5-10% sensitivity range.

This may be shown also for the entire Savinja river basin upstream of Temerje gauging stations is the surface waters nitrogen budget displayed on Figure 9. Again, we do not present all the background documentation, based on the same
presumptions as in the case of Savinja upstream of Letuš.

Mean annual discharge in the year 1998 was 43.1 m³/s, with mean annual nitrogen concentration being 1.94 mg N/l. This yields for 1998 an annual nitrogen export estimate 2636.9 tons N/year.

We see that in the case of the analysed river basin the estimated nitrogen input differs from the hydraulically and chemically evaluated nitrogen output just slightly more than 5%. From the gauging station data, the nitrogen mass output of the river basin has a 5-10% verification error margin. With this in mind is the observed nitrogen mass input - output difference meaningless.

Figure 5: Process “non-fertile land” for the Savinja river basin upstream of Letuš
Figure 6: Nitrogen budget of Savinja river basin upstream of Letuš

7 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. For a better internal regionalisation of the analysed river basins with respect to 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 quite often a bigger source of total nitrate pollution as readily believed. While this is relatively obvious for urban areas, it is less clear for dispersed settlement. No data enabling a check of nitrate reduction efficiency of the existing septic tanks and other equivalent sanitary facilities are available. So, part of the pollution deriving from disperse settlement is actually attributed to agriculture.
Figure 7: Nitrogen budget of Savinja river basin upstream of Tremerje

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References

