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# CONTRIBUTION OF AGRICULTURAL SOURCES TO NUTRIENT LOAD GENERATED ON THE RUSSIAN PART OF THE BALTIC SEA CATCHMENT AREA

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Agricultural production is one of the main sources of nitrogen and phosphorous inputs to the water bodies. Quantifying nutrient input from agriculture is needed both to develop effective environmental measures and to justify the technologies to be applied with due account for local natural and climatic conditions. Several related national studies have been conducted since 2015. Institute for Engineering and Environmental Problems in Agricultural Production (IEEP) methodology was used for this purpose. It determines the nitrogen and phosphorus content in the arable layer, including N and P amounts applied with mineral and organic fertilisers. Such factors as soil type and texture, the distance to the water bodies and the land use structure are used to estimate the nutrient input to the water bodies. In addition, the consistency of manure handling technologies with Best Available Techniques (BAT) principles is taken into account through introduction of relevant coefficients. Calculation results according to IEEP methodology were used in the follow-up general assessment of the nutrient load on the water bodies from different sources with the use of Institute of Limnology Load Model. Satisfactory correspondence between the assessment results and the values calculated using the monitoring data confirmed the adequacy of the above assessment procedure. Following its outcomes, the nutrient reduction potential of agricultural sources is approximately 10–20 %.

*Keywords: agricultural source, Baltic Sea, nutrient load, reduction potential, water body*

## INTRODUCTION

According to the previous HELCOM assessment (HELCOM, 2011.), agriculture in the catchment area of the Baltic Sea is a major source of nutrient inputs, which intensify eutrophication of sea waters.

The HELCOM role in reducing the negative impact of agricultural production in the Baltic Sea Region is, among others, to regulate the load on environment from this type of source, to develop recommendations and approaches for environmentally friendly farming, and to monitor the compliance with requirements based on current environmental data.

To evaluate the effectiveness of measures, aimed to reduce nutrients loading from various sources, agricultural ones included, HELCOM implements regular pollution load compilation based on the Contracting Parties data. The methodology for determining the contribution of various sources is found in HELCOM Pollution Load Compilation Guidelines (HELCOM, 2015).

Previous HELCOM assessments considered the Russian load by aggregated source categories, without addressing its diffuse part separately and contribution of agricultural production, in particular.

IEEP has developed a methodology for calculating the diffuse load of nitrogen and phosphorus on water bodies from agricultural production (Briukhanov, 2015). This methodology was applied in a number of national research projects and made it possible to estimate the annual nitrogen and phosphorus loading from agricultural production in the Russian part of the Baltic Sea catchment area in 2014. Moreover, it allows to estimate the potential reduction of nutrient load when introducing Best Available Techniques (BAT) for intensive livestock farming.

## RESEARCH METHODS

Diffuse load of nitrogen and phosphorus depends on farm specialisation, type and structure of soils, crop rotation, technologies in place and type of applied mineral and organic fertilisers.

Two sources of nitrogen and phosphorus removal are considered to determine the diffuse load: soil and fertilisers (mineral and organic). The leaching from farmland soils is calculated taking into account the depth of the arable and root zones, which is 20-25 cm for the North-West Federal District. Significantly prevailing part of nitrogen and phosphorus leaching occurs precisely from this soil layer.

The amount of nitrogen and phosphorus input to water bodies is determined by the area of farmland (ha), belonging to agricultural organisations, private family farms and personal smallholdings.

According to the methodology developed by IEEP, the nutrient input to the water bodies from the fields of agricultural enterprises ($L_{agr}$, *t/yr*) is calculated by the formula:

$$L_{agr} = \sum_i A_i\big(M_{soil\ i}K_1 + \big(\alpha_1 M_{min\ i} + \alpha_2 M_{org\ i}\big)K_6\big)K_2K_3K_4K_5/1000 \tag{1}$$

where $M_{soil\ i}$ - nutrient content in the arable soil layer, (kg/ha);;

$M_{min\ i}$ and $M_{org\ i}$ - application rates of mineral and organic fertilisers on the fields of the *i*-th agricultural enterprise (kg/ha);

$A_i$ - the land area of the *i*-th agricultural enterprise (ha);

$\alpha_1$ - the coefficient of the plant uptake of nutrients from mineral fertilisers;

$\alpha_2$ - the coefficient of the plant uptake of nutrients from organic fertilisers;

$K_1$ - the coefficient of nutrients leaching from the arable soil layer;

$K_2$ - the distance coefficient between the agricultural land and the hydrographic network;

$K_3$ is the coefficient of soil type (by its origin);

$K_4$ is the coefficient of soil texture;

$K_5$ is the coefficient, which takes into account the structure of farmland, i.e. ratio of arable land, perennial grasses, meadows, pastures;

$K_6$ is the coefficient, which takes into account the introduction of BAT.

Spatial analysis methods were used to determine the location of farmland in relation to the water bodies and the subsequent calculation of $K_2$ coefficient.

All coefficients are dimensionless. Values of the coefficients were determined on the basis of an integrated analysis of literature sources (Koren'kov, 1976; Amberger, Schweiger, 1973; Barrows, Kilmer, 1963) and IEEP experimental data and were further used to calculate the nutrient load from farmland in the North-West Russia (Table 1).

Table 1. The values of the coefficients from equation

| Coefficient | *N* | *P* |
|---|---|---|
| $\alpha_1$ | 0.3 | 0.03 |
| $\alpha_2$ | 0.1 | 0.02 |
| $K_1$ | 0.03 | 0.008 |
| $K_2$ (from 50 to 500 m) | 0.6 | 0.6 |
| $K_2$ (from 500 to 2000 m) | 0.2 | 0.2 |
| $K_2$ (above 2000 m) | 0.1 | 0.1 |
| $K_3$ (soddy podzolic soil) | 1.0 | 1.0 |
| $K_3$ (carbonate soil) | 1.2 | 1.4 |
| $K_3$ (peat soil) | 0.8 | 1.0 |
| $K_4$ (heavy-textured loam and sandy loam soils) | 1.0 | 1.0 |
| $K_4$ (light-textured loamy sand and sand soils) | 1.8 | 2.0 |
| $K_5$ (cattle breeding) | 0.46 | 0.37 |
| $K_5$ (crop production) | 0.88 | 0.76 |
| $K_5$ (poultry breeding) | 0.46 | 0.37 |
| $K_5$ (pigs breeding) | 0.46 | 0.37 |
| $K_6$ (without applying BAT) | 1.0 | 1.0 |
| $K_6$ (with BAT) | 0.25 | 0.1 |

To determine the coefficients, which define the share of nitrogen and phosphorus leaching, the characteristics of sod-podzolic soils were taken as the basis because they are the most common type on the studied areas. The average nutrient removal with the crop yield was taken as 120 kg/ha for nitrogen and 17.6 kg /ha for phosphorus (Koren'kov, 1976).

Based on the agrophysical properties of soils, which form the studied watersheds, the values of nitrogen and phosphorus content in the arable layer of sod-podzolic soil of the North-West region of Russia were taken as 3600 kg/ha and 1050 kg/ha, respectively.

The amount of organic and mineral fertilisers applied in the catchment areas has a significant effect on nitrogen and phosphorus leaching. The average nitrogen and phosphorus content in organic fertilisers produced by currently used technologies is presented in Table 2. Manure output was determined with due account for manure removal methods and wastewater and bedding content (Bryukhanov et al., 2014)

Table 2. The content of nitrogen and phosphorus in organic fertilisers

| Manure-based organic fertiliser | N, kg/t | P, kg/t |
|---|---|---|
| cattle | 4.8 | 0.8 |
| pigs | 2.4 | 0.7 |
| poultry | 10 | 2.1 |
| sheep and goats | 4.8 | 0.8 |
| horses | 8 | 0.9 |

To calculate the nutrient load from agricultural land, two data sources were used:

- the data on particular agricultural enterprises;
- districts-wise statistical data, adjusted according to the example of particular farms.

Coefficients for estimating the reduction of the nutrient input to the water bodies when applying BAT were defined using the method of logical-linguistic modelling based on expert assessments. (Briukhanov et al., 2016).

To assess the contribution of all sources to the annual removal of nitrogen and phosphorus from the Russian part of the Baltic Sea catchment area, Institute of Limnology Load Model was applied (Pozdnyakov et al., 2016).

Total nitrogen and total phosphorus (in unfiltered sample) load ($L$, *t/yr*) from the catchment area is calculated as the sum of the nutrient loading from all sources on the hydrographic network:

$$L = L_{agr} + L_c + L_{P1} + L_a \quad (2)$$

where $L_{agr}$ - loading from agricultural enterprises, (t/yr);
$L_c$ - loading from natural and anthropogenic (modified) landscapes not currently affected by agricultural impact(t/yr);
$L_a$ - atmospheric deposition on the surface of the catchment area, (t/yr);
$L_{P1}$ - point sources of nutrients, which discharge their sewage into the hydrographic catchment network.

All components have the dimension of tons annually. The load generated by agricultural enterprises is calculated according to the method proposed by IEEP.

Statistical data for 2014 concerning availability of agricultural land, animal and poultry stock, and applied mineral fertilisers was used to determine the diffuse load of nitrogen and phosphorus from the Russian part of the Baltic Sea catchment area. The manure output and the content of total nitrogen and phosphorus were determined in accordance with the Management Directive for Agro-Industrial Complex RD-APK 1.10.15.02-08 (Methodical recommendations …, 2008; Umweltbundesamt, 2015), the methodology developed in IEEP, and using the outcomes of several studies (Bryukhanov et al., 2014). The generalized baseline data for the areas under investigation are presented in Table 3 (KTBL, 2011).

Table 3. Initial data to calculate the diffuse load

| Catchment area | Cattle stock, ths. livestock units (LSU) | Poultry stock, ths. LSU | Pig stock, ths. LSU | Other animals, ths. LSU | Total amount of manure produced, ths. t/yr | Total amount of N in the manure, t/yr | Total amount of P in the manure, t/yr | Agricultural area, ths. ha | Total amount of N applied with min.fertlis., t/yr | Total amount of P applied with min.fertlis., t/yr |
|---|---|---|---|---|---|---|---|---|---|---|
| Gulf of Finland South-East coasts (GoF S-E coast) | 6.4 | 14.2 | 1.2 | 0.4 | 335.7 | 1925.4 | 352.0 | 13.2 | 914.8 | 311.5 |
| Gulf of Finland North-East coasts (GoF N-E coast) | 7.8 | 46.3 | - | - | 496.5 | 3480.0 | 671.6 | 14.5 | 3588.0 | 778.0 |
| Narva River immediate catchment | 4.6 | 0.0 | 0.0 | 0.4 | 176.9 | 849.2 | 141.5 | 10.9 | 1293.0 | 226.0 |
| Neva River immediate catchment | 17.6 | 117.7 | 26.7 | 0.6 | 1445.9 | 9205.8 | 1833.1 | 36.6 | 2353.1 | 600.5 |
| Luga River catchment | 41.0 | 19.7 | 3.8 | - | 1831.9 | 9185.4 | 1579.1 | 120.1 | 7205.0 | 1517.8 |
| Ladoga Lake | 25.7 | 87.1 | 22.7 | 1.3 | 3367.0 | 18984.0 | 3648.0 | 36.1 | 1687.1 | 525.0 |
| Onega Lake | 14.4 | 4.9 | 4.1 | 0.6 | 639.0 | 3100.0 | 536.8 | 27.5 | 800.1 | 147.1 |
| Lake Ilmen | 31.2 | 59.7 | 81.8 | 5.1 | 2500.0 | 11725.8 | 2281.0 | 184.3 | 4157.5 | 1047.0 |
| Peipsi Lake | 36.1 | 1.4 | 81.5 | 3.9 | 4058.0 | 16479.0 | 3130.0 | 142.5 | 4180.6 | 1084.5 |
| Vistula Lagoon | 23.8 | 17.9 | 53.6 | 0.2 | 980.0 | 4600.0 | 785.4 | 62.4 | 11031.7 | 3518.0 |
| Curonian Lagoon | 23.5 | 1.3 | 9.4 | 0.2 | 1465.0 | 6458.0 | 1233.0 | 159.1 | 4325.8 | 1379.5 |

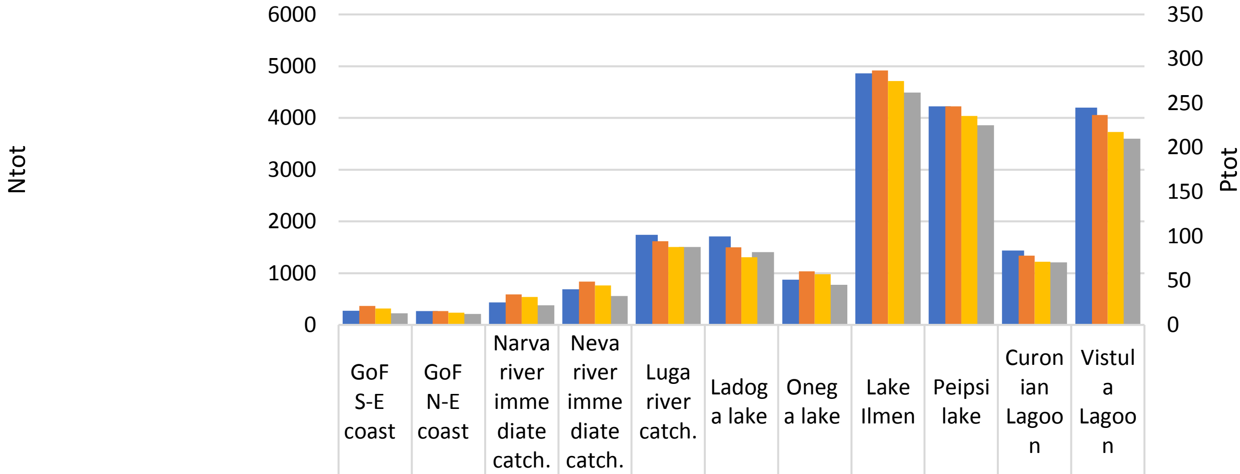
**RESULTS AND DISCUSSION**

Analysis of the baseline data shows that immediate catchments of the Ladoga Lake and the Neva River, as well as the rivers of the North-Eastern coast of the Gulf of Finland, may be exposed to higher nutrient loads from livestock enterprises. The increased risk of excessive nitrogen and phosphorus inputs is due to the presence of large poultry farms in the specified area.

In the catchment areas of Southeast and North-Eastern coasts, the immediate catchment of the Narva River and the catchment area of Ladoga Lake the sod-podzolic and sod-carbonate soils dominate, in some places peaty soils, which, in terms of texture, are equally divided into heavy and light soils. The drainage areas of the lakes Onega, Ilmen and Peipsi, have mainly sod-podzolic and peaty soils, mostly light. The soils of the catchment areas in Kaliningrad Region basically have a sod-podzolic base, mainly light in texture.

As a result of agricultural activities, 85,992.5 tons of manure nitrogen and 16,191.5 tons of manure phosphorus within farm animal manure are produced and used annually on the areas under consideration. Around 43165 tons of nitrogen and 11435 tons of phosphorus are applied to the fields with mineral fertilizers.

The following values of the actual and potential nutrient loading on the nearest water bodies due to agricultural activities result from the calculations using IEEP methodology (Figure 1).




| | GoF S-E coast | GoF N-E coast | Narva river immediate catch. | Neva river immediate catch. | Luga river catch. | Ladoga lake | Onega lake | Lake Ilmen | Peipsi lake | Curonian Lagoon | Vistula Lagoon |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ntot load in 2014, t/yr | 275 | 269 | 436 | 689 | 1739 | 1708 | 874 | 4862 | 4223 | 1437 | 4200 |
| Ntot potential load (BAT), t/yr | 224 | 212 | 381 | 560 | 1506 | 1409 | 775 | 4490 | 3857 | 1209 | 3601 |
| Ptot load in 2014, t/yr | 21 | 16 | 34 | 49 | 94 | 87 | 60 | 287 | 246 | 78 | 237 |
| Ptot potential load (BAT), t/yr | 19 | 14 | 32 | 44 | 88 | 76 | 57 | 275 | 236 | 71 | 217 |

Figure 1. Actual and forecasted nitrogen and phosphorus inputs to water bodies from agricultural production

The results show that in some cases the load in catchments with many animals is lower than that in the catchment with smaller number of animals. This is because nitrogen and phosphorous content in the arable soil layer is usually bigger than nitrogen and phosphorus inputs with mineral and organic fertilizers. Thus, arable land area is of decisive importance in most cases. Diffuse loading from the areas with large percentage of agricultural land will almost always be higher, even if the animal stock is relatively small (e.g. if we compare Ladoga Lake and Vistula Lagoon catchment areas). Only under certain conditions, when the animal density is very high, this factor will determine the nutrient diffuse loading. In addition, the migration conditions, denoted in equation 1 through coefficients $K_2$-$K_5$, also play an important role. Thus, the cumulative value of these coefficients for the Narva catchment area is 3 times higher than the corresponding value for the North-Eastern coast of the Gulf of Finland - hence the diffuse load is higher from Narva River catchment despite the lower animals stock. It is sufficient to note that the value of nitrogen leaching can differ by 1.8 times and phosphorus leaching by 2 times depending on soil texture, under other conditions being equal.

According to the calculation results the average annual leaching from 1 ha of cropland is 28 kg of nitrogen and 1.8 kg of phosphorus. The value for nitrogen falls within the range of corresponding values determined for 35 catchments in the North and Baltic Sea regions (Jakobsson, 2012). The amount of phosphorus leaching is somewhat overestimated in comparison with the results of the mentioned assessment for other river catchments areas in the Baltic Sea Region.

Initial load reduction at source, related with BAT introduction on the large farms, is 25% for nitrogen and 10% for phosphorous (as shown in table 1). The total reduction of the nitrogen and phosphorus load on the water bodies owing to BAT introduction is estimated at the level of 12% for total nitrogen and 7% for total phosphorus. The average estimated decrease in nitrogen and phosphorus loading from agricultural land owing to BAT introduction in animal husbandry is about 10%. The effectiveness of BAT introduction is higher in the areas, which experience significant impact from livestock enterprises, e.g. the Northeast coast of the Gulf of Finland and the immediate catchment of the Neva River. However, it does not exceed 20%.

The final values of the nutrient load from the territory of the catchment areas were calculated by the mathematical model created in the Institute of Limnology, are shown in the table 4.

Table 4. Values of the nutrient load from the territory of catchment areas

| Catchment area | Total nutrient load, generated on the catchment area | | Contribution of agricultural sources | |
|---|---|---|---|---|
| | Ntot, t/yr. | Ptot, t/yr. | Ntot | Ptot |
| GoF S-E coast | 7958.3 | 412.9 | 3% | 5% |
| GoF N-E coast | | | | |
| Narva river immediate catch. | 25781.3 | 1108.5 | 2% | 3% |
| Neva river immediate catch. | | | | |
| Luga river catch. | | | | |
| Ladoga lake | 32638.8 | 1859.5 | 4% | 4% |
| Onega lake | 20228.1 | 1298.5 | 4% | 4% |
| Lake Ilmen | 26809.2 | 1501.7 | 17% | 19% |
| Peipsi lake | 13721.3 | 931.4 | 29% | 26% |
| Curonian Lagoon | 3220.6 | 167 | 42% | 45% |
| Vistula Lagoon | 9524.2 | 781.6 | 43% | 30% |
| Total: | 139881.8 | 8061.1 | 14% | 15% |

In 2014 the contribution of agricultural sources, with reference to watersheds, to the actual nutrient load generated on the Russian part of the Baltic Sea catchment area was estimated by these values and amounted to 15% average.

The contribution of agricultural production to nutrient load generated on the Russian part of the Baltic Sea catchment area varies considerably between different parts of the basin: from 2% to 43% for nitrogen, and from 5% to 45% for phosphorus. The reason for this is the intensity of agricultural activities, and the loading rate from other sources. In a number of cases, even sufficiently intensive agricultural production plays an insignificant role in the formation of the overall load (for example, in the catchment area of the Ladoga Lake, North-East coast of the Gulf of Finland, etc.).

## CONCLUSIONS

For the first time, the calculations identified the share of agricultural production in the total nutrient load generated on the Russian part of the Baltic Sea catchment area. Currently, IEEP is upgrading the applied methodology in experimental studies to adjust the leaching coefficients for nitrogen and phosphorus.

The proposed methodology, with due account for further improvement, can be used in the Russian national reporting for HELCOM as well as to identify the technological standards for the Russian BAT reference books.

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