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# Emissions of nitrogen and phosphorus into rivers from agricultural land – selected controversial issues

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## Abstract

The research methodology for determining the sources of nutrients responsible for the eutrophication of rivers and seas, as well as the extent of their load in particular drainage basins, has for many years been at the centre of vigorous discussion. In the Oder and Vistula river basin, apart from the calculation of monthly and annual loads of nitrogen and phosphorus, based on the discharge and chemical monitoring data of waters, the MONERIS (Modeling Nutrient Emissions in River Systems) model has also been applied in determining nutrient sources. This article, on the basis of a comprehensive review of the professional literature, shall cast a critical eye over six issues that have been at the centre of past robust discussion: 1) determining the balance of N and P in agriculture, 2) the effects of a significant improvement in sewage treatment, 3) impact of technology on agriculture, 4) determination of nutrient retention in drainage basins, 5) impact of tile drainage practices on the leaching of nutrients, 6) as well as the accuracy of calculations made according to the MONERIS model. It would appear that for practical purposes it is sufficient to determine given loads of N and P from the drainage basins of particular rivers, as well as to adjust the above mentioned model, or indeed – resign from the unproven methodology of determining nutrient sources in rivers.

**Key words:** *emission, load, MONERIS model, nitrogen, phosphorus, point/non-point sources, retention, river eutrophication*

## INTRODUCTION

The eutrophication of rivers, lakes and the Baltic Sea is a condition in an aquatic ecosystem where high nitrogen and phosphorus concentrations stimulate the growth of algae, which leads to an imbalanced functioning of the system. Point sources (cities, industry), non-point (diffuse) sources (agriculture, forestry, natural background, atmospheric deposition) of nutrients were differentiated. The HELCOM (Helsinki Convention) nutrient load calculation for the Baltic defines 75% of nutrient as waterborne and 25% as atmospheric deposition [HELCOM 2004].

Atmospheric deposition (mainly of nitrogen) is a diffuse source depending on air pollution. The Fifth Baltic Sea Pollution Load Compilation [HELCOM

2011] was published in 2011 with data from calendar years 1994 to 2008. In this time about 45% of the total input to the sea of nitrogen (N) and phosphorus (P) originated from diffuse sources, 12% N and 20% P from point sources. Agriculture contributed approximately 70% to over 90% of the anthropogenic diffuse riverine N load and 6–80% of the corresponding P load. The nutrient load was presented as calculated and flow normalized, and the second method diminished the influence of high or low precipitation and runoff, as well as providing a more accurate evaluation of load trends. The waterborne PLC guidelines [HELCOM 2006], however, do not include a common methodology for quantifying diffuse sources or delivery pathways for catchment retention. Retention of nutrients is defined as removal of N and P in surface

waters of river systems including lakes and river valleys, influenced by biological and sedimentation processes. Retention in the river catchment area has diminished the net nutrient load transported by rivers to the sea. The riverine load apportionment for nutrients during the year and between relevant years is strongly influenced by meteorological and hydrological factors, soil conditions (permeability, sorption) and technology used in wastewater treatment stations.

The question may be put whether agriculture is in fact the largest source of nutrients in rivers and the greatest threat to Baltic Sea eutrophication or indeed, whether this is a matter of high population density with many factories and different sewage treatment plant facilities? Many investigations show that the load of nitrogen and phosphorus from agriculture to the rivers has been overestimated [ERIKSSON *et al.* 2007; HOWDEN *et al.* 2010; JARVIE *et al.* 2006; KRONVANG *et al.* 2005; PROCHÁZKOVÁ *et al.* 1996; RANKINEN *et al.* 2007; RÄIKE *et al.* 2003; TUMAS 2000]. One can therefore ask which is the greater source of pollution: intensification of agricultural production methods or ineffective sewage treatment in cities and industry plants.

The objective of this study is to contribute to the professional literature through an overview of some selected problems connected with river eutrophication, which could provide a better insight into this economic and scientific problem. The study therefore shall cover the usefulness of the nutrient surplus method, impact of building and modernization of sewage treatment plants, impact of farm management practices on nutrient loss, retention in the river basin, impact of tile drainage on nutrient leaching and nutrient emissions into rivers calculated using the MONERIS model.

## SELECTED PROBLEMS ANALYZED BY RIVER EUTROPHICATION STUDIES

### USEFULNESS OF THE NUTRIENT SURPLUS METHOD

One sign of nitrogen sources in every catchment area is the nitrogen balance “on the soil surface”, recommended by the Organization for Economic Cooperation and Development [OECD, Eurostat, 2007]. In Poland this balance in the periods 1995–1990 and 2006–2010 was about 60 kg N·ha<sup>-1</sup> and between 1991–2005 about 40 kg N·ha<sup>-1</sup> [FOTYMA *et al.* 2012]. Because there was a poor correlation between nitrogen leaching and surplus, as well as between farm management practices and nitrogen loss, the nutrient balance was not a good indicator of nutrient leaching in the landscape and cannot be used for calculation of river eutrophication threat [ERIKSSON *et al.* 2007; OENEMA *et al.* 2005; RANKINEN *et al.* 2007; SALO, TURTOLO 2006; STÄLNACKE *et al.* 2004; VAGSTAD *et al.* 2004].

In the Netherlands on a national scale, decreasing the N surplus of 1 kg·ha<sup>-1</sup> has decreased nitrate leaching to groundwater only by 0.08 kg·ha<sup>-1</sup> and to surface waters by 0.12 kg·ha<sup>-1</sup> [OENEMA *et al.* 2005]. In Finland a similar decrease of N surplus has decreased N-leaching by 0.3 kg·ha<sup>-1</sup>, but there was no correlation between N balance and N leaching on the farm level [RANKINEN *et al.* 2007]. The nitrogen balance shows only the potential for pollution and not the actual nitrogen leaching [SALO, TURTOLO 2006]. Nitrogen surplus does not inform about nitrogen pathways (erosion, surface runoff, tile drainage, groundwater) from agriculture to rivers and sea, but is taken into account by calculation of nitrogen emission in the MONERIS model [BEHRENDT *et al.* 2005; FUCHS *et al.* 2010].

In the Oder and Vistula rivers basin the N-surplus decreased from 58 kg·ha<sup>-1</sup> in 1980 to 39 kg·ha<sup>-1</sup> in 2000 (much lower than in West European countries). This, however, did not lead in 1990–1994 to a rapid reduction in N concentrations in these rivers [ERIKSSON *et al.* 2007]. The OECD method of nitrogen surplus calculation does not show a visible connection with the observed area specific nitrogen load. In the Warta River Basin for example, a region with intensive agriculture and high population density, in 2008–2011 the nitrogen surplus was 65.4 kg N·ha<sup>-1</sup> and had no visible connection with the observed area’s specific nitrogen load of 3.78 kg N·ha<sup>-1</sup>·year [ILNICKI *et al.* in review].

Also no relationship could be developed between total phosphorus (TP) loss and P surplus on agricultural land in the 35 Nordic and Baltic investigated micro-catchments [KRONVANG *et al.* 2007].

### IMPACT OF BUILDING AND MODERNIZING SEWAGE TREATMENT PLANTS

As a result of high population density, industry development and human activity, there was a production of a large amount of waste water that contained many nutrients. Depending on the national income and economy, the creation of sewerage networks and building of sewage treatment plants (STPs) with increased nutrient removal was realized in the last 50 years in the Baltic Sea basin. This process has taken a long time and in many countries it is not finished. In most new UE member countries the building and modernizing of STPs started at the end of the 20<sup>th</sup> century. In these countries the major influence of badly purified sewage on water quality in rivers was visible with the naked eye all over the landscape. The situation in Poland (Tab. 1) illustrates the change in this activity in the country and for the Warta River Basin in particular.

In 1997, wastewater in the Warta River Basin was purified to 52.3% only with mechanical treatment, 23.1% sewage with secondary and 7.1% with tertiary treatment. In 2002, the analogical values were 34.6%, 38.5% and 21.7% respectively. In the years

**Table 1.** Sewerage networks and sewage treatment plants in Poland: 1990–2010

Year	Sewerage network km	Number of STPs	Number of biological sewage treatment plants with increased nutrient removal
1990	26 515	467	0
1995	33 511	643	42
2000	51 100	965	256
2005	80 100	949	386
2010	107 500	855	396

Source: GUS [1996; 2011].

1993–2002, the amount of sewage from 20 large towns localized in the Warta River Basin decreased from 320.7 to 186.2 hm<sup>3</sup>. Numerous STPs with tertiary treatment were built and in 2002 they existed in 13 of the 20 largest towns [ILNICKI *et al.* 2008]. In the Warta River Basin the influence of building and modernizing STPs in Kalisz, Łódź and Poznań was analyzed in the period 1992–2011 [ILNICKI *et al.* in review]. In 2011, in the Warta River Basin, 45% of sewage was purified with tertiary treatment and 10% with secondary treatment. On the other hand, in all towns counting more than 100 000 inhabitants, there existed a STP equipped with tertiary treatment [GUS 2011]. The largest STPs in the Warta River Basin have been constructed and modernized: Kalisz in 2001–2003, Poznań in 1996–2001 and Łódź in 1997–2002 (Tab. 2). In these STPs a large reduction of the phosphorus load (73% in Łódź, and 38% in Kalisz and Poznań) is visible after their construction or modernization and the reduction of nitrogen load is accordingly very high in Łódź (43%), lower in Poznań (18%) and Kalisz (5%). Between 1992–2000 and 2001–2011 in the Warta mouth the annual mean nutrient concentration decreased, through STP modernization from 3.07 mg N·l<sup>-1</sup> and 0.34 mg P·l<sup>-1</sup> to 2.65 mg N·l<sup>-1</sup> and 0.21 mg P·l<sup>-1</sup> and much more in the Ner River [ILNICKI *et al.* in review].

**Table 2.** Construction and modernization of some STPs in the Warta River Basin: change of nutrient load in rivers in the period 1992–2011

City	River	Water quality station	Period	Annual area specific calculated load, kg·ha <sup>-1</sup>	
				nitrogen	phosphorus
Kalisz	Prosna	Ruda Komorska – mouth	1992–2000	7.60	0.45
			2001–2011	7.25	0.28
Łódź	Ner	Chelmno – mouth	1992–2000	21.78	2.65
			2001–2011	12.43	0.72
Poznań	Warta	Oborniki	1992–2000	8.39	0.45
			2001–2011	6.91	0.28

Source: ILNICKI *et al.* [in review].

In Poland between 1988 and 2008, the reduction in N loads discharged from STPs into surface water in the Vistula and Oder basin, reached respectively 4540 Mg and 10 400 Mg, and the reduction in P loads 1430 Mg and 1650 Mg [PASTUSZAK *et al.* 2012]. As result of these large investments an observed decrease in N concentration in the Oder and Vistula is the result of nutrient removal in municipal STPs with tertiary treatment and not a drop in fertilizer use in agriculture [ERIKSSON *et al.* 2007].

#### FARM MANAGEMENT PRACTICES AND THEIR IMPACT ON NUTRIENT LOSSES

A sudden increase of arable land in Great Britain in 1940 (from 30 to 60%) through ploughing of permanent grassland and lawn, resulted in the release of mineral N and an increase of its concentration in the River Thames. A second increase was the result of agriculture intensification between 1960 and 1980 [HOWDEN *et al.* 2010].

A different situation took place in Central and Eastern Europe after 1989. This was the start of a political transition, characterized by a drop in mineral fertilizer and manure application, decrease in livestock stocking, closure of some obsolete factories and modernization or construction of new sewage treatment plants. Their influence on river eutrophication was studied in the Czech Republic, Estonia, East Germany, Hungary, Latvia, Lithuania, Poland and Slovakia.

In Lithuania in 1992–1996 in comparison with 1986–1991, fertilizer application was 84.6% lower and the amount of animals in agriculture decreased by 70%, but unexpectedly the NO<sub>3</sub>-load increased at the Nemunas River mouth about two times as a result of the mineralization of large pools of organic N that had accumulated over many years in the river. Phosphates enter into rivers mainly from towns and only 16% from agriculture, and the correlation between P concentration in rivers and cropland area was poor [SILEIKA *et al.* 2002; 2006]. Also in this context, TUMAS [2000] noted only weak downward trends in Lithuanian rivers. In Latvia, the purchase of mineral fertilizers, between 1987 and 1996 abruptly decreased by a factor of 15 and the number of livestock by a factor of four. This decrease in agriculture intensity had led to only a slow (especially by N) response in Latvian rivers [STALNÄCKE *et al.* 2003]. Studies on three rivers in Estonia, Latvia and Hungary, indicate that large cuts in the use of commercial fertilizers do not necessarily induce an immediate response, particularly in medium-sized and large catchments areas [STALNÄCKE *et al.* 2004]. In this light no downward trends were found by PROCHÁZKOVÁ *et al.* [1996] in the Vltava River in the Czech Republic. PEKÁROVÁ, PEKÁR [1996] reported that nutrient concentrations in surface water in the Ondava River in Slovakia have decreased after a substantial reduction in the use of fertilizers. Considerable decreases in nutrient concentrations have also been observed in the Elbe River

[HUSSIAN *et al.* 2004]. An observed decrease in N concentration in Oder and Vistula rivers in the 1990s is not ascribed to a drop in fertilizer use, but to better management of urban point sources [ERIKSSON *et al.* 2007].

STALNÄCKE *et al.* [2003] rightly point out that variability in nutrient concentrations in agricultural dominated rivers are regulated and dependent on many factors:

- the soil nutrient pool and farming practices such as cropping systems, long-term fertilization intensity and soil cultivation techniques,
- hydrological pathways and their influence on retention,
- temporal variability in flow conditions and
- in stream, riverine and lake retention.

Other factors that were highly important were the stream density, atmospheric deposition, soil type and structure, mineralization and hydro-meteorological variables [ARHEIMER, LIDÉN 2000], as well as the groundwater depth [OENEMA *et al.* 2005]. Intensive studies in Finland in the period 1981–1997 show that weather-driven fluctuations in discharge is usually the main reason for changes in nutrient loss, not (or very little) the impact of changes in agricultural production structures or management practices [VUORENMAA *et al.* 2003].

The above mentioned studies show that the contribution of diffuse nitrogen sources from agriculture to rivers and the Baltic Sea might have been overestimated and the impact of agricultural practices on surface water eutrophication is not as high as mentioned in the Pollution Load Compilation in 2004. According to this document, diffuse losses contribute 58% of the waterborne N and 49% of P input to the Baltic Sea, while only 10% N and 25% P originate from point sources [HELCOM 2004].

#### RETENTION IN THE RIVER BASIN

Only some nitrogen compounds introduced to rivers from various sources actually reach their mouth. Because about half of the N emission is lost in gaseous form, the riverine export it represents is only 11–40% of total N input [VAN BREEMEN *et al.* 2002]. According to the **River Removal of Nitrogen** model, 60% of input in rivers is removed during transport through the river network, not only in the main river [SEITZINGER *et al.* 2002]. In rivers with a low specific runoff of 4–6 l·km<sup>2</sup>·s<sup>-2</sup> in Central Europe, the retention rate is 60–75% P and 50–75% N [BEHRENDT *et al.* 2005] from the input into rivers. In seven Lithuanian and Estonian river basins the retention capacity in surface water was 67–78% TN and 24–63% TP of the input, higher in lakes than in streams [POVILAITIS *et al.* 2012].

The retention rate is much higher in lakes, wetlands in river valleys and rises with a longer flowing distance in rivers with low longitudinal slope and unconsolidated soils. During the long transport in the

soil, ground water, ditches and river systems, nutrients can be absorbed by solid particles and transformed, settling on the streambed or floodplain. These are in turn taken up by plants and microbes, stored in soils and groundwater, or transformed by bacteria (denitrification). Such processes were termed now as river basin retention. They increased with longer water residence time and show seasonal cycles and long-term changes, different for dissolved, organic or particle bound forms [LEPISTÖ *et al.* 2006; RÄIKE *et al.* 2003; WITHERS, JARVIE 2008]. If a catchment is characterized by slow-flow processes, smaller N loads will be detected in the receiving surface water due to increasing losses through denitrification in the groundwater [VAGSTAD *et al.* 2004]. The respective differences between rivers, seasons and years has been high, depending on the transit time and geomorphology. The river monitoring data represent the net nitrogen and phosphorus loads after transformation (denitrification, sedimentation, adsorption) and retention in the riverine systems.

Because the retention is very high and the precipitation and runoff causes a large inter-annual nutrient load variability, the use of nutrient load on the river mouth is justified, not a determination of load source provenance (contribution of different sources), whose contribution is at present described on the basis of numerous hypotheses.

#### TILE DRAINAGE IMPACT ON NUTRIENT LEACHING

Field drainage in the form of installed pipes has been realized on large areas in Poland and Germany and has been seen to improve the use of arable land by accelerating water transport to ditches in wet periods. Drain discharge in the MONERIS (**M**odeling **N**utrient **E**missions in **R**iver **S**ystems) Model [BEHRENDT *et al.* 2005] is calculated according to KRETSCHMAR [1977] for investigations from Schleswig-Holstein, on the basis of the assumption that 50% of precipitation in winter and 10% in summer drains away. The nitrogen load is determined on the basis of its concentration in drainage water runoff.

These are measures that are rather high for Polish conditions, for they assume that in annual precipitation of 530 mm the average drainage runoff in Central Poland would amount to approximately 140 mm. Existing data indicates that it is lower by 15% annual precipitation; that is 80 mm [MARCILONEK *et al.* 1980; WANKE 2011]. Research for two decades [KOSTRZEWA 1977] has shown that arable land drainage in Poland is responsible for 10–20% of annual precipitation; most often around 80–100 mm. The average annual runoff from the entire Warta Basin amounts to 22.7% of precipitation; approximately 120 mm, which underscores how inappropriate it is to take into consideration, in the context of the Oder and Vistula rivers, measurements determined for northern Germany. In Finland in June 1994–December 1996, tile drains overlaid with gravel, accounted for 51%

of the total runoff (439 mm) and 79% of the total N-losses [PAASONEN-KIVEKÄS *et al.* 1999], but this is not typical for Poland.

In the MONERIS model the N concentration in drain water was calculated on the basis of N surplus (reduced by a factor of 0.85 through denitrification), and the P concentration in sand as 0.2, and in loam as 0.06 mg P·l<sup>-1</sup> [FUCHS *et al.* 2010]. Because the N surplus is very high and not correlated with N leaching, the nitrogen emission from drainage waters for tile drainage is really much lower than used in the MONERIS model. A review of the professional literature in Poland of drainage waters has shown that analysed concentrations of 1 dm<sup>3</sup> most often do not exceed 20 mg N-NO<sub>3</sub> and 0.07 mg PO<sub>4</sub> [LIPIŃSKI 2000]. In an European review of micro-catchments, soil erosion and surface runoff was the dominant (53.4%) diffuse pathway [KRONVANG *et al.* 2007]. Concentrations of phosphorus in drain water are very low (<0.1 mg P·l<sup>-1</sup>), in the main containing soluble inorganic P, which as a rule is lower than in the neighbouring stream and moreover, it is difficult to quantify the relationship between soil P concentrations measured in the topsoil and at the drain depth [DILS, HEATHWAITE 1999]. Soluble reactive phosphorus concentrations are higher in rare surface runoff, than in tile drains (about 25), ditches (15–20) and the groundwater (15 mg P·l<sup>-1</sup>) [GELBRECHT *et al.* 2005].

The accepted runoff from drainage waters according to the MONERIS model, is for Polish conditions significantly overstated, similar to nitrogen concentrations in drainage waters calculated on the basis of a N-surplus, as a result of which the respective loads are many times higher than in reality.

#### NUTRIENT EMISSIONS INTO RIVERS CALCULATED USING THE MONERIS MODEL

The MONERIS (Modeling Nutrient Emissions in River Systems) Model in recent years has been used to calculate the extent of nitrogen and phosphorus loads that reach surface waters from various sources, causing their eutrophication. The above model has

been used in the drainage basins of numerous German rivers [FUCHS *et al.* 2010; KREINS *et al.* 2010], as well as for the Oder and Vistula in the periods 1993–1997 and 1995–2008 [BEHRENDT *et al.* 2005; KOWALKOWSKI *et al.* 2012]. In the basins of the largest rivers across Germany and its neighbours (Danube, Rhine, Ems, Weser, Elbe, Oder) calculated according to MONERIS, the emission for the periods 1993–1997 and 2003–2005 from background and agricultural sources amounted to approximately 60% and 75% respectively for nitrogen, and accordingly 35% and 45% for phosphorus.

The average deviations, however, in the period 1983–2005 between the measured and modelled river loads are 30.0% for total nitrogen and 38.4% for total phosphorus [FUCHS *et al.* 2010] respectively, which can be seen as a large difference. In 1995–2008 the nutrient load calculated on the monitoring basis was lower (13% for the Vistula River and 19% for the Oder River) than calculated with the MONERIS model [PASTUSZAK, IGRAS 2012]. The MONERIS research hypothesis argues that drainage and ground waters discharge part of the excess of nitrogen from the soil calculated according to OECD, which in the drainage basin of the Weser would be equivalent to a high area specific load of 13.4 kg N·ha<sup>-1</sup>·year<sup>-1</sup> and 0.31 kg P·ha<sup>-1</sup>·year<sup>-1</sup> [KREINS *et al.* 2010].

Calculations conducted on the basis of the above model have demonstrated that point sources were responsible for 14.1% nitrogen and 32.3% phosphorus in the Weser River in 2003 [KREINS *et al.* 2010], whereas groundwater and drainage water runoff amounted to as much as 72.3% N and 41.6% P respectively. In the Oder for the period 1993–1997 point sources contributed to 42.6% N and 73.9% P on average, whereas groundwater was responsible for 53.1% N and 12.3% P accordingly. For the period 1995–2008 in this context the respective data showed 16% N and 41% P, while for groundwater and drainage runoff 72% N and 14% P (Tab. 3). It can be therefore seen that there is an unusually high share of nitrogen from groundwater in comparison to point sources.

**Table 3.** MONERIS calculated nitrogen and phosphorus emissions for the Oder River Basin

Pathways	Nitrogen load, %			Phosphorus load, %		
	Oder 1993–1997	Oder 1995–2008	Weser 2003	Oder 1993–1997	Oder 1995–2008	Weser 2003
Atmospheric deposition on the water surface	3.1	4.0	0.9	1.0	2.0	0.5
Surface runoff	0.4	4.0	10.9	1.0	15.0	12.2
Soil erosion	0.8	4.0	1.8	11.8	28.0	13.4
Tile drainage	<b>26.0</b>	<b>48.0</b>	<b>29.5</b>	<b>3.2</b>	<b>8.0</b>	<b>9.7</b>
Groundwater interflow	<b>27.1</b>	<b>24.0</b>	<b>42.8</b>	<b>9.1</b>	<b>6.0</b>	<b>31.9</b>
Point sources (STPs, industrial discharges)	36.4	12.0	11.0	62.2	24.0	22.6
Paved urban area	6.2	4.0	3.1	11.7	17.0	9.7
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: 1993–1997 [BEHRENDT *et al.* 2005] and 1995–2008 [KOWALKOWSKI *et al.* 2012] and for Weser River Basin: 2003 [KREINS *et al.* 2010].

Modelling studies (MONERIS), performed for the Vistula and Oder rivers basins for the years 1995–2008, have shown that ca. 70% of nitrogen emission was via groundwater and tile drainage. The contribution of the tile drained area in the Oder River Basin was much higher (48% N, 8% P) than in the Vistula River Basin (29% N, 4% P) [KOWALKOWSKI *et al.* 2012].

The MONERIS model argues that the drainage runoff increases that of groundwater from agricultural areas. But only in wet periods does drainage accelerate the runoff, without changing its level for the year per se. This suggests, taking into account the rate of tile drainage, which in the basin of both rivers ‘contributes’ 26–29.5% of nitrogen and 3.2–9.7% of general phosphorus load, there are no grounds to argue that the preceding increase emission from non-point sources.

In an European overview the main diffuse pathway for total P loads in 17 macro-catchments (250–11 000 km<sup>2</sup>) simulated with the MONERIS model, shows that from point sources it constituted respectively 28.2%, from soil erosion and surface runoff 53%, groundwater 14%, tile drainage water 2.8% and 1.3% from atmospheric deposition. A multiple regression analysis performed between the export load of TP ( $P_{ex}$ ) and percentage of agricultural land  $A$ , area of surface water in the catchment  $S$ , population density in the catchment  $P$  as inhabitants per km<sup>2</sup>, total catchment area  $CA$  in km<sup>2</sup> and runoff  $R$  in mm, shows a significant relationship between the phosphorus export and only three explanatory variables:

$$P_{ex} = 0.0011R + 0.0020P - 0.0015S$$

$$N = 16, r^2 = 0.65$$

The main factors governing phosphorus export were population density and catchment hydrology, as well as area of surface water in the catchment as a proxy for phosphorus retention – not the area of agricultural land per se [BECHMANN, STÄLNACKE 2005; KRONVANG *et al.* 2007].

Point rather than diffuse (agricultural) sources of P therefore provide the most significant risk for river eutrophication, even in rural areas with high agricultural losses. Diffuse sources generate increased concentration with flow resulting from agricultural runoff during rainfall events. This regression analysis shows a quite different situation than the MONERIS model. Point rather than diffuse (agricultural) sources of phosphorus, it can be seen, provide the most significant risk for river eutrophication, even in rural areas [JARVIE *et al.* 2006]. The contribution of diffuse N sources from agriculture to the observed deterioration trends of the Baltic Sea ecosystem might therefore have been overestimated [ERIKSSON *et al.* 2007].

Atmospheric deposits of nitrogen resulting from atmospheric pollution contribute well over 10 kg N·ha<sup>-1</sup>·p.a.<sup>-1</sup> in Poland and Germany, and are accounted for in the above model only for surface wa-

ters, but not the entire drainage basin. As a consequence, data at unimportant levels is considered, while at the same time, fundamental non-point sources in the river drainage basin are omitted.

The use of the MONERIS model, the basis of numerous research hypotheses for investigations conducted on studies of various scale (in very complex physical, chemical and biological processes taking place in the drainage basin network), places into question the reliability of research results and places into doubt numerous important issues in this context. The data therefore can be seen to be clearly overstated, in particular in respect to non-point sources. The issue at heart after all, lies not in a ‘laboratory’ determination of nutrient sources, or indeed pointing a finger at those ‘guilty’ in respect to the eutrophication of rivers. Rather, we require a precise determination of given monthly and annual loads (kg·ha<sup>-1</sup>·year<sup>-1</sup>) calculated in particular river basins. HELCOM [2013] divided emissions only on the basis of waterborne, airborne and split point sources into municipal wastewater treatment plants, industry and fish farms. In this way the main sources of emission for N and P responsible for the eutrophication of surface waters were presented.

## CONCLUSIONS

The OECD method of nitrogen surplus calculation does not show a visible connection with the observed area specific nitrogen load. Also no relationship could be developed between total phosphorus (TP) loss and P surplus on agricultural land. A result of large investments is an observed decrease in N concentration in the Oder, Vistula and Warta rivers where there can be observed a large nutrient removal in municipal STPs with tertiary treatment, no a drop in fertilizer use in the agriculture. The contribution of diffuse nitrogen sources from agriculture to rivers and the impact of agricultural practices on surface water eutrophication therefore might have been overestimated. Because the nutrient retention in river basins is very high, and the precipitation and runoff causes a large inter-annual nutrient load variability, nutrient load on the river mouth should be taken into account, and not a determination of load source provenance. The broadly used MONERIS model of data collection for drainage waters runoff is significantly overstated in the context of Polish physical geography, similar to the concentration of nitrogen in drainage waters calculated on the basis of N-surplus, resulting in the calculated loads being many times higher than in reality. The extent of nutrient emission calculated according to the MONERIS model is overstated, requiring a particular correction in respect to diffuse sources, in which the respective share of groundwater and drainage waters raises the greatest doubt. In this context therefore it could be argued that instead of aiming to determine the approximate extent of numerous nutrient sources in the river basin, it would suffice for

practical purposes to determine area-specific loads of N and P annually from the basins of particular rivers.

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Piotr ILNICKI

## Ładunki azotu i fosforu wprowadzane do rzek z terenów rolniczych – wybrane dyskusyjne problemy

STRESZCZENIE

**Słowa kluczowe:** azot, emisja, eutrofizacja rzeki, fosfor, ładunek, model MONERIS, retencja, źródła punktowe i powierzchniowe

Sposób określania źródeł pochodzenia składników biogennych powodujących eutrofizację rzek i mórz oraz wielkości ich ładunków w poszczególnych zlewniach od lat wywołuje liczne dyskusje. W zlewni Odry i Wisły – poza obliczaniem miesięcznych i rocznych ładunków azotu i fosforu na podstawie przepływów i wyników monitoringu wód – stosowano również model MONERIS określający źródła pochodzenia składników biogennych. Na podstawie obszernego przeglądu literatury w artykule w sposób krytyczny przedstawiono sześć dyskusyjnych problemów dotyczących: obliczenia bilansu N i P w rolnictwie, skutków znacznej poprawy w zakresie oczyszczania ścieków, wpływu technologii stosowanych w rolnictwie, określania retencji składników biogennych w zlewni, wpływu drenowań na wymywanie tych składników oraz prawidłowości obliczeń wykonywanych z użyciem modelu MONERIS. Do celów praktycznych wystarczające wydaje się określenie jednostkowych ładunków N i P odprowadzanych corocznie ze zlewni poszczególnych rzek oraz skorygowanie wymienionego modelu lub zrezygnowanie z niepewnego określania źródeł pochodzenia biogenów w rzekach.

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### General remarks of the reviewer to the paper „Emissions of nitrogen and phosphorus into rivers from agricultural land – selected controversial issues”

1. The article focuses on alleged weak points of the MONERIS model, ending up in an alleged overestimation of diffuse sources (mainly agriculture, especially drainage water). Yet the article is not an overall evaluation in the sense of a swot-analysis of the MONERIS model, as it is rather one-sided on supposed weaknesses. We therefore recommend to clearly characterize the article as a critical personal position (e.g. in a subtitle) based on a literature review and a contribution to a difficult and controversial discussion (as there is no new scientific information in the article).
2. In our agency (FEA Germany) we'll have the next discussion on the MONERIS-model and HELCOM load reporting in October. We will discuss the selected controversial issues mentioned by the authors. In the sense of a fair and open discussion we recommend to give the scientists working in the development of the MONERIS model a chance to respond on the article and to outline further improvement in one of the next volumes of the Journal.
3. MONERIS is one of the national models (in this case for Germany) approved by HELCOM for national reporting within PLC projects. As we understand Poland is generally free to have its own approach and method approved. Therefore it would be helpful to give a short outline how Poland elaborates its contributions to PLC projects, especially in the Vistula basin. For the Oder river we think it does make sense to use the same approach by all countries with parts of the catchment area. But Poland is not forced to use MONERIS, if this model is regarded as unfit for Polish physical geography, and may use approved own tools. The article gives no overview in this matter.
4. The final conclusion, that instead of using (doubtful) models (like MONERIS) it would be better to determine area-specific nutrient loads of selected river basins (and then extrapolate on whole Poland?) is not elaborated further. Will this be done in one of the following issues? Questions like representatively, extrapolation, costs and methods of analysis would be extremely interesting.
5. Generally, I do hope that the article is meant to contribute to scientific discussion in a constructive way, i.e. to improve the scientific basis for environmental politics; hopefully it is not the intention of the authors to provide arguments for not doing any reduction measures in agriculture as the scientific basis is (as they claim) insufficient and inappropriate, the importance of diffuse sources is overestimated etc. The implementation of the Baltic Sea Action Plan should not be put at stake. As regards the methods we understand there is a considerable for the HELCOM member states to provide own approaches based on own scientific activities.
6. First of all if the MONERIS model and the results are reviewed a short description or characterization of the model should be given. One has to bear in mind, that MONERIS is aiming at describing nutrient inputs from

hydrological catchments at the mesoscale or smaller macroscale. This means that input of N and P from areas larger than a few 100 km<sup>2</sup> should be described reliably in most situations provided that sufficient detailed input data are available. So deviations at a smaller scale are inevitable and beyond the scope of the model whereas the results at a larger scale could be considered reliable, especially as historic changes could be modeled in accordance with monitoring time-series.

7. It seems as if the authors do not know the model MONERIS and the model results in detail because some assumptions made by the authors are wrong:
  - N-deposition: The authors point out: *Atmospheric deposits of nitrogen resulting from atmospheric pollution contribute well over 10 kg N/ha/p.a. in Poland and Germany, and are accounted for in the above model only for surface waters, but not the entire drainage basin. As a consequence, data at unimportant levels is considered, while at the same time, fundamental non-point sources in the river drainage basin are omitted.*  
This assumption is false: For other pathways the deposition is included indirectly – please see model distribution and description of input data.
  - nitrogen surplus: surplus are central input data to describe this source. Based on this data transport processes are described and depending on catchment characteristics inputs can be calculated (spatial distributed). Furthermore, system reaction periods are not taken into account.
  - usage of different model versions: The MONERIS model had been developed and some moduls (pathways) have been changed during the period of 2006 and 2014. Therefore, it carefully be proffed if for the comared studies regarding the Oder River System the same model versions had been used. For the interpretation you need to take methodical changes into account.  
Furthermore, the possibility of spatial distributed prediction should not be seen as a disadvantage. MONERIS is able to consider specific catchment characteristics, regional differences and temporal changes. But quality of model results depends on quality of input data.
8. Without using models it is almost impossible to predict spatial distributed nutrient inputs and the main sources/pathways. Furthermore, it will be impossible to identify effective measures to reduce nutrient inputs to surface waters (e.g. to fulfill the requirements of WFD and river basin management).
9. Furthermore, we want to point out that river catchments are mostly slow responding systems (except e.g. point sources) regarding changes in land management. This depends e.g. on groundwater retention periods of several years up to decades. Changes in land management in most cases do not causes immediate changes in water quality (concentrations).

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