JOURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
ISSN 1648–6897 print/ISSN 1822-4199 online
2013 Volume 21(2): 141–151
doi:10.3846/16486897.2012.663088

ASSESSMENT OF NITROGEN POLLUTION REDUCTION OPTIONS IN THE RIVER NEMUNAS (LITHUANIA) USING FYRISNP MODEL

Antanas Sigitas Šileika[a], Mats Wallin[b], Kazimieras Gaigalis[c]

[a]*Water Research Institute, Aleksandras Stulginskis University, Parko g. 6, Vilainiai, LT-58102 Kėdainiai, Lithuania*
[b]*Department of Aquatic Science and Assessment, Swedish University of Agricultural Sciences, Box 7050, 750 07 Uppsala, Sweden*
[c]*Alekandras Stulginskis University, Water Research Institute, Mituvos g. 9, LT-50134 Kaunas, Lithuania*

Submitted 06 Mar. 2011; accepted 23 Nov. *2011*

Abstract. The paper quantifies and discusses diffuse and point sources total nitrogen (TN) inputs as well as retention and TN reduction options in the catchment of the main Lithuanian River Nemunas. Modelled average TN export between 2000–2006 from the River Nemunas catchment to the Baltic Sea was 37620 tonnes TN yr^{-1} according to the data oriented FyrisNP model. Loads of TN from diffuse and point sources as well as retention have been estimated for five subcatchments of the River Nemunas including the external load from Belarus. Agriculture contributes 74.6 to 89.5% of the TN load, increasing with the percentage of arable land and load from point sources. The main point source input is poorly treated wastewater at Kaunas city. The contribution from forest land to the TN load increases from 2.2% to 15.8% with an increase in forest land from 28.5 to 56.9% of the total subcatchments area. The highest retention of TN (30.7%) was observed in the Neris river subcatchment with the lowest hydraulic load (5.55 m yr^{-1}). Scenario modelling suggests that the reduction target for Lithuania for nitrogen input to the Baltic Sea by 11700 tonnes can be achieved by installing biological treatment in sewage treatment plants in all district cities and by converting 20% of arable land to pastures or implementation of other equivalent measures in agriculture. Assessment of the FyrisNP model results shows that the model can be successfully applied for river basin management planning in catchments outside the area where the model originally has been developed.

Keywords: water pollution; environmental processes modelling; catchment; nitrogen; concentration; load; retention.

Reference to this paper should be made as follows: Šileika, A. S.; Wallin, M.; Gaigalis, K. 2013. Assessment of nitrogen pollution reduction options in the river Nemunas (Lithuania) using FyrisNP model, *Journal of Environmental Engineering and Landscape Management* 21(2): 141–151. http://dx.doi.org/10.3846/16486897.2012.663088

Introduction

Nitrogen (N) and phosphorus (P) are the two main nutrients responsible for-eutrophication of coastal and marine waters (Fogelberg 2003). Their load to the Baltic Sea has resulted in negative environmental effects including algal blooms and oxygen depletion in deep waters. The Member States of HELCOM adopted an action plan to drastically reduce pollution of the Baltic Sea and restore its good ecological status. To achieve the target for N, Lithuania agreed to a reduction of the yearly N load of 11750 tonnes by 2021 (HELCOM 2007). The EU Water Framework Directive (Anon 2000) prescribes to develop river basin management plans and to achieve good water status by 2015, including coastal waters but not marine waters. Marine waters are, however, covered by the EU Marine Directive with the aim to achieve good environmental status of the EU's marine waters by 2020 (Anon 2008).

Many investigations have been carried out on nutrient concentration trends and loads in rivers in various countries (Keeney, DeLuca 1993; Johnes, Burt 1993; Vuoristo 1998; Stalnacke *et al.* 1999a, b; Vuorenmaa *et al.* 2002; Klavins *et al.* 2001; Hussian *et al.* 2003; Magner *et al.* 2004; Iital *et al.* 2010). The eutrophication of costal lagoons and open seas is analysed by Vitousek *et al.* (2004); Nixon *et al.* (1996); Wulf and Rahm (1988). Despite the actions undertaken by HELCOM countries, the overall eutrophication status of the Baltic Sea is still unacceptable (HELCOM 2008).

Heidi Vuoristo (1998) suggests that water quality in Finnish lakes and rivers subjected predominantly to point source loading has improved, however, in many areas deterioration of water quality is reported to be caused primarily by non-point source pollution, particularly from agriculture. Having investigated water quality in Finish rivers and small agricultural and forest catchments Jussi Vuorenmaa *et al.* (2002) claims that changes in nutrient losses are mainly caused by weather-driven fluctuations in discharge while no or very little impact of changes in agricultural production, structures, or management practices can be observed. After normalization of the Elbe River environmental data, having removed natural fluctuations from the collected data, Mohamed Hussian *et al.* (2003) found N and P loads are strongly influenced by water discharge.

Corresponding author. Antanas Sigitas Šileika
E-mail: sigitas.sileika@asu.lt

www.tandfonline.com/teel

Ahti Lepisto *et al.* (2006) claims that in Finland agriculture contributes on average 38% of the TN export, varying between 35–85% in the south-western basins and 0–25% in the northern basins. Forest land contributes on average 9% of the TN export. Of the TN input to Finnish river-systems, 0% to 68% is retained in surface waters and/or peatlands, with a mean retention of 22%. The highest retention of TN (36–68%) has been observed in the basins with the highest percentage of lake.

There is very little data available about the nutrient fate in the Baltic countries where dramatic changes in industry, agricultural production and social life have taken place in the last decade (Jansons *et al.* 2002; Klavins *et al.* 2001; Bagdžiūnaitė-Litvinaitienė 2004; Povilaitis 2008; Iital *et al.* 2010).

Stalnacke *et al.* (1999b) state that the six largest rivers in eastern and southern parts of the Baltic Sea basin are responsible for about half the total riverine export of N and P to the sea. Long-term detailed investigations of nutrient concentration and load in the Nemunas River, the fourth largest river in the Baltic Sea basin, are of the utmost importance for the successful management of Baltic Sea eutrophication. To create cost effective action plans for reducing nutrient loadings to marine areas, it is important to know the contributions from the various sources in the catchment, and the retention in rivers and lakes.

The present study focuses on quantification of total nitrogen (TN) loads from diffuse and point sources as well as retention in the Nemunas River catchment.

The main objective of this study is to determine the measures needed to achieve the 11700 tonnes (30%) nitrogen reduction target in the Baltic Sea Action Plan undertaken by the Lithuanian Government.

1. Study area and data sets

The present study focuses on TN loads to the River Nemunas from the Lithuanian territory at the monitoring site Smalininkai in the River Nemunas and outlets of the main tributaries the Merkys, the Neris, the Nevėžis and the Dubysa (Fig. 1). Monitoring site Smalininkai (110 km from the mouth) was selected because there are no reliable water quality measurements at the river mouth. The modelling includes a calibration period of seven years (2000–2006).

The River Nemunas basin has a total area of 97,864 km^2, of which 46,695 km^2 is in Lithuania, 45, 389 km^2 in Belarus, 3,174 km^2 in Kaliningrad district of Russia, 2,517 km^2 in Poland and 88 km^2 in Latvia (Gailiusis *et al.* 2001). The study area covers 70.4% of the Lithuanian territory (Gailiusis *et al.* 2001).

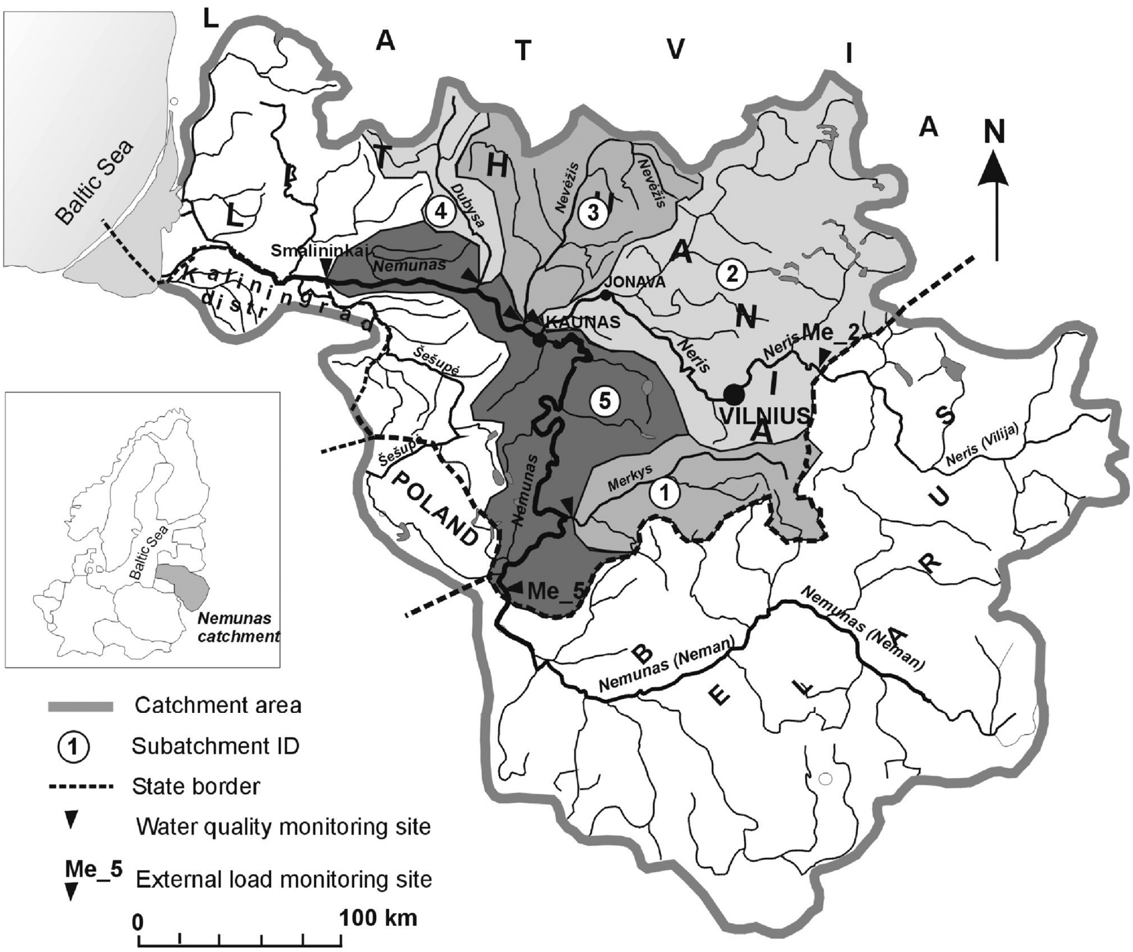

Fig. 1. The River Nemunas catchment and monitoring sites

The River Nemunas basin receives annual precipitation of 520 to 800 mm (Poluckaja 2000). Precipitation is higher at the western hilly areas than in the south-east. Inter year variation in precipitation can be as high as 40%. Snow melt water contributes about 40%, ground water 35% and rain fall 25% of the total River Nemunas runoff. The climate is influenced by the Baltic Sea causing instability of the weather such as frequent thaws in winter and sunny summers being as common as wet ones. Annual average temperature varies between 5.5 and 6.5 °C. The coldest month is January, with temperature –9 to –4.5 °C. Average July temperatures are 17 to 19 °C, with a maximum 34–37 °C (Poluckaja 2000). The long-term mean River Nemunas water discharge to the Baltic Sea is 703 $m^3 s^{-1}$ (Gailiusis *et al.* 2001), it accounts for 19.6% of the total runoff to the Baltic Proper sub basin.

Farming lands cover 56% of the River Nemunas basin, with arable land and grasslands accounting for 73.7 and 26.3% of the agricultural land use. Forest, shrubs and bogs account for the land cover in the remainder of the basin. Sandy loams and sands with a high potential for N leaching account for 63% of the total basin area.

Land use data were obtained from a GIS data base for Lithuania which combines CORINE 2006 land cover for Lithuania (Vaitkuviene *et al.* 2008) and a vector data base LTDBK50000-V (National Land Service 2004). All of the measured water flows and water quality data were obtained from the Lithuanian Hydrometeorological Service and the Lithuanian Environmental Protection Agency (former Lithuanian Joint Research Centre). Leaching coefficients for different land use and precipitation were calculated from monthly measurements in three small agricultural catchments located in western, central and eastern parts of Lithuania. (Sileika *et al.* 2005; Šileika *et al.* 2010).

2. Methods

2.1. Sampling methods and analysis

The measured TN concentration in rivers was obtained from the water quality data base, maintained by Regional Environmental Protection Departments. Twelve samples per year were analysed in all river water quality monitoring sites and point source pollution outlets.

Monthly concentrations of TN (one sample per month) and average monthly values of river water flow were used for calculation of the TN load. Monthly runoff volume was calculated from daily water measurements data. Linear interpolation method (Rekolainen *et al.* 1989) was used for calculation of the nutrient load l_i.

$$l_i = \sum_{m=1}^{n} c(t_m) \cdot q(t_m), \tag{1}$$

where: l_i – mean load, kg yr^{-1}; $c(t_m)$ – average concentration of the two neighbouring samplings, mg l^{-1}; $q(t_m)$ – runoff volume for the period t_m around the sampling time, m^3; m – sampling number.

Water quality analysis was conducted according to standard methods (Anon 1994) in the chemical analytical laboratory of the Water Research Institute. The laboratory has approbation for the surface water quality analyses form Lithuanian Environmental Protection Agency. The TN was determined by oxidation with peroxodisulphate to nitrate, followed by photometry using phenol disulfoacid. Difference between the determined TN and TN in standard solution should be no more than 10%.

2.2. FyrisNP model and input data

There are a number of tools for nutrient loads calculation and source apportionment in river catchments (Euroharp 2003; Grizzetti *et al.* 2005; SWAT 2005). The mass balance based FyrisNP model is one such tool which calculates the source-apportioned load and transport of TN and TP in rivers (Lindgren *et al.* 2007; Hansson *et al.* 2008b). The main scope of the model is to assess the effects of different nutrient reduction measures on the catchment scale. The time step for the model is one month (or week), and the spatial resolution is on the subcatchment level. Retention, i.e. losses of nutrients in rivers and lakes through sedimentation, up-take by plants and denitrification, is calculated as a function of water temperature, potential TN concentration and lake area, and areas of lakes and streams. The model has two calibrated retention parameters, *kvs* (retention parameter, m yr^{-1}) and c_0 (temperature parameter, dimension less) which are estimated using time series of measured TN concentrations (Hansson *et al.* 2008a).

The data used for calibrating and running the model can be divided into time-dependent data, e.g. time series on observed nutrient (TN) concentration, water temperature, runoff and point source discharges, and time-independent data, e.g. land-use information, lake area and stream length and width (Fig. 2).

Due to sedimentation, uptake by plants and denitrification some TN is retained as it travels from the headwaters downstream. Permanent removal or retention of TN in rivers or lakes is calculated in the model as a function of weather, water temperature, surface water TN concentration, runoff, and lake and river water surface areas (Hansson *et al.* 2008b).

Nitrogen retention is expressed by the coefficient R of nitrogen retention in the catchment:

$$R_T = \frac{T_a \cdot kvs}{q_s + kvs}, \tag{2}$$

where: kvs – an empirical coefficient; T_a – a temperature adjustment factor given by:

$$T_a = \begin{cases} 0, & T < 0 \\ c_0 + \dfrac{T(1-c_0)}{20}, & 0 \le T \le 20 \\ 1, & T > 20 \end{cases}, \tag{3}$$

where: T – the water temperature, °C; c_0 – an empirical calibration parameter.

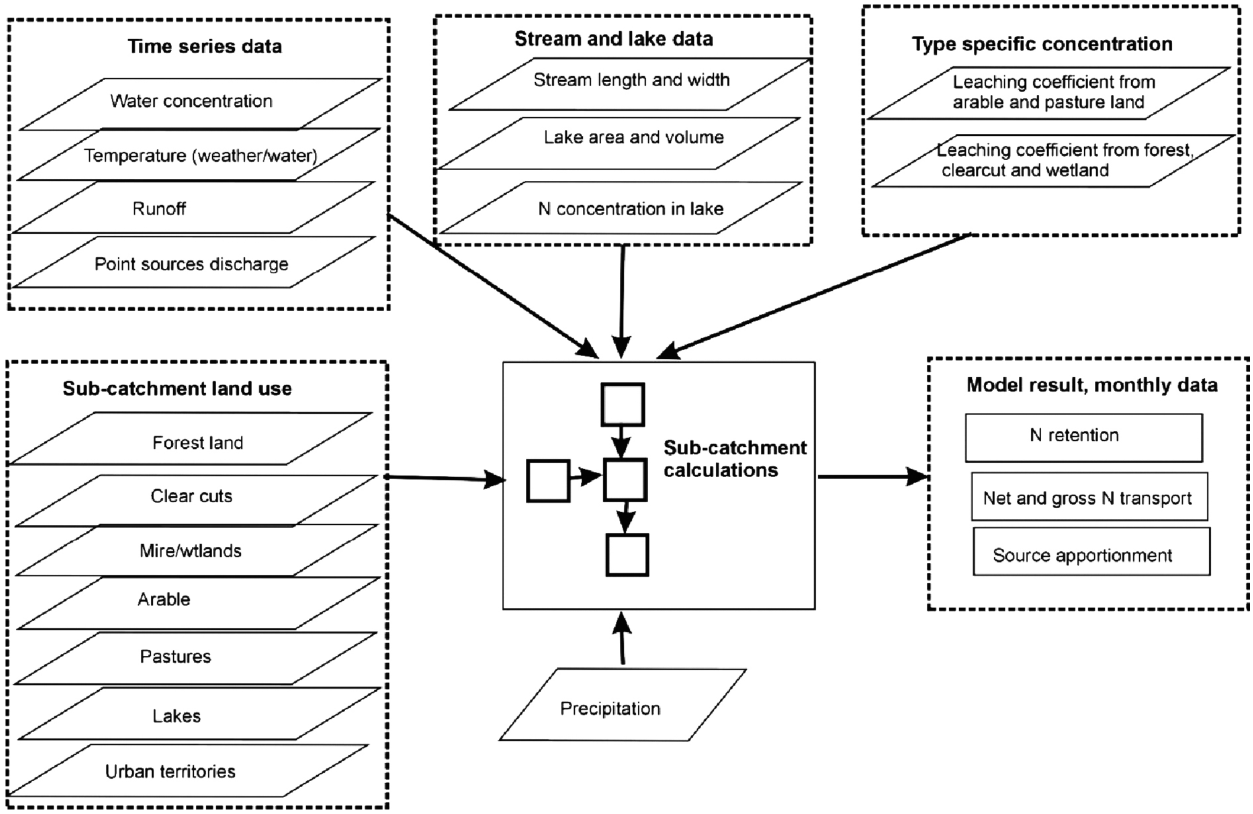

Fig. 2. The structure and characteristics of inputs and outputs of the model

The parameter c_0 determines the level of retention reduction by temperatures between 0 °C and 20 °C. The hydraulic load, q_s (m yr^{-1}), is calculated as follows:

$$q_s = \frac{Q}{A_{lake} - A_{LM} + A_{stream}}, \tag{4}$$

where: Q – water specific runoff from subcatchment, l s^{-1} km^{-2}; A_{lake} – the total surface area of all lakes in the given sub-catchment, m^2; A_{LM} – the area of the lake treated in the separate lake module (if one such exists in the sub-catchment), m^2; A_{stream} – the surface area of all streams in the sub-catchment, m^2.

In order to perform simulations with the FyrisNP model, an Excel-file containing all input data is required (Table 1). The Excel data file contains between eight to ten different worksheets depending on the features used (Hansson *et al.* 2008b). The inclusion of the External load worksheet means that the loading from upstream parts of the river catchment is included in the model without any source apportionment. This worksheet is used to include the TN load to the rivers Nemunas and Neris from Belarus territory.

2.3. Statistical evaluation

In order to evaluate the fit of simulated to observed values, two statistical measures are used in the FyrisNP model: the model efficiency, E and the correlation coefficient, r.

The definition of model efficiency (Nash, Sutcliffe 1970) is:

$$E = 1 - \frac{\sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n}(y_i - x^{mean})^2}, \tag{5}$$

where: n – the number of observations; x^{mean} – the mean value of all observations, mg l^{-1}; y_i and x_i – the observed and modelled concentrations, respectively, mg l^{-1}.

E = 1 implies that the measured and modelled series are identical, and E = 0 indicates that the simulation is no better than a straight line representing the average value of the observations (Hansson *et al.* 2008a).

Relative percentage error e was calculated according to Sofia Fogelberg *et al.* (2004):

$$e = \frac{\sqrt{\frac{1}{n}\sum(y_i - x_i)^2}}{\frac{1}{n}\sum y_i} \cdot 100, \tag{6}$$

where: y_i – measured concentration, mg l^{-1}; x_i – calculated concentration, mg l^{-1}; n – number of measurements.

AS well statistical evaluation of the model efficiency model validation was carried out for two independent data series (1997–2001 and 2002–2006) in the river Nevėžis (subcatchment #3). The obtained values of the empirical retention coefficients from calibration were preserved during validation.

Table 1. The River Nemunas catchment (Lithuania) characteristics at the monitoring sites

Subcatchment name	The Merkys	The Neris (Lithuania)	The Nevėžis	The Dubysa	The Nemunas* (Lithuania)
Subcatchment ID	#1	#2	#3	#4	#5
Area, km^2	3792.6	13709.7	6140.5	1965.9	7262.8
Total lakes area, km^2	47.9	455.6	26.2	11.2	265.8
Total streams length, km	1428.0	5123.0	7994.0	1249.0	4386.0
Total stream area, km^2	11.4	22.1	18.3	5.9	21.8
Forest, km^2	2052.0	4916.3	1662.3	545.5	2405.5
Clearcuts, km^2	100.2	259.0	87.5	28.8	121.9
Mire, km^2	45.9	118.4	39.3	31.5	34.6
Arable, km^2	972.1	4835.4	3669.5	991.6	3130.6
Pasture, km^2	510.4	2587.6	447.6	299.3	1005.4
Open, km^2	3.1	23.0	1.5	2.1	6.0
Built, km^2	41.8	367.9	115.3	38.2	201.0
Urban, km^2	7.9	125.3	73.0	11.7	70.2
Altitude, m	80.0	90.0	60.0	60.0	50.0
TN deposition on lakes, kg ha^{-1} yr^{-1})	18.72	18.72	18.72	18.72	18.72
TN leaching from arable land, mg l^{-1**}	5.2	9.4	10.5	5.8	10.5
TN leaching from pasture, mg l^{-1**}	2.2	4.5	4.5	2.8	5.0

* The Nemunas (Lithuania) subcatchment consists the area between the subcatchments of the Merkys, the Neris (Lithuania), the Nevėžis and the Dubysa).

** Annual mean concentration.

3. Results

3.1. Model validation and calibration

Monte Carlo simulations using measured vs modelled TN concentrations was used to find values of parameters c_0 and *kvs*. These parameter values were then used in manual calibration of TN concentration in FyrisNP.

For the model validation the river Nevėžis subcatchment #3 was selected because a rather long and consistent TN data series was available. After Monte Carlo simulations (300 simulations) optimum values of $c_0 = 0.86$ and the coefficient $kvs = 0.78$ best fitted the data series 1997–2001. Model efficiency E = 0.58 and correlation coefficient r = 0.76 were achieved in calibration of TN concentration in FyrisNP. Using the same calibration parameters for the data set 2002–2006 resulted in model efficiency E = 0.43 and correlation coefficient r = 0.68. Model efficiency and correlation coefficient were slightly lower for the validation period but in acceptable agreement with the calibration results. The modelled net load of TN from the River Nemunas catchment includes retention in all upstream subcatchments and in the Nemunas River itself. In the calibrated model set up the temperature adjustment coefficient c_0 and calibration parameter *kvs* were the same for all subcatchments and the whole data set 2000–2006. Monte Carlo simulations resulted in optimum retention coefficients $c_0 = 0.65$ and the coefficient $kvs = 0.82$. The model efficiency $E = 0.61$ and the correlation coefficient $r = 0.78$ imply good congruence between observed and modelled data series. E and r are calculated based on all selected pairs of the observed and simulated concentrations lumped before calculation (Hansson *et al.* 2008a). The simulated TN loads plotted against the observed monthly ones during the analysed period (2000–2006) at the monitoring site #5 correspond well (Fig. 3).

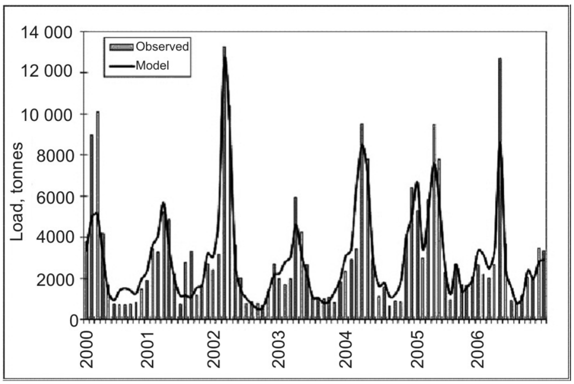

Fig. 3. Observed and modelled TN monthly loads at the outlet of the River Nemunas subcatchment #5

Winter and early spring exhibit peak values where observed values exceeds model results for most of the years. One possible reason for a mismatch between modeled and observed data could be temporal variability in TN concentration. Grab samples for water quality analysis are taken once a month and these values are considered representative for the whole month in FyrisNP. Temporal variability in concentrations causes more uncertainty in estimated loads during periods of peak flow than during low or mean flow periods. In order to achieve more accurate value of mean monthly load, the frequency of water sampling as well as flow proportional sampling must be taken into account. Difference between modelled and measured data decrease when yearly mean loads are used instead of monthly concentrations. The discrepancy between the modelled and observed mean TN load values for seven year is only 0.14% (Fig. 4).

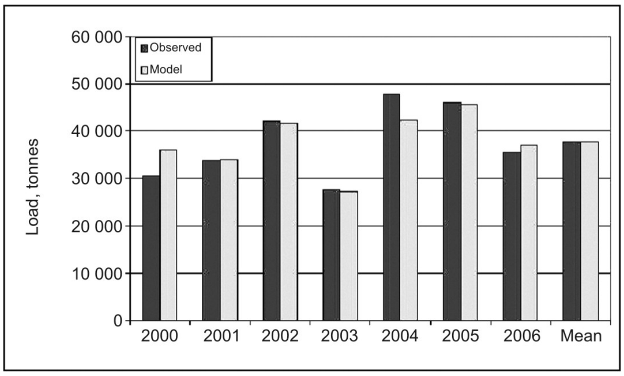

Fig. 4. Observed and modelled TN yearly loads at the outlet of the River Nemunas subcatchment #5

3.2. TN contribution to the watercourses and retention

The internal TN load sources (gross contribution) is calculated for each catchment and summed for the entire simulation period (Fig. 5).

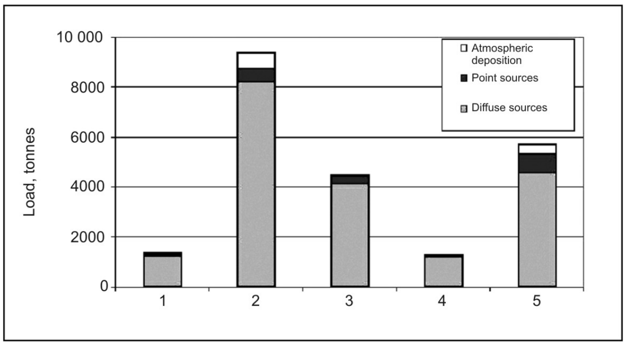

Fig. 5. Internal TN load source apportionment for each subcatchment

The largest total load (93611 tonnes) is to the watercourses of the subcatchment Neris, #2. This subcatchment also has the largest area (24 942 km^2 including 11 100 km^2 in the Belarus territory) and subsequently the largest TN contribution from non-point sources – 81,991 tonnes. The largest point-source contribution (7316 tonnes, 44.6% of the total point-source load) enters to the River Nemunas subcatchment #5. The main source of pollution is Kaunas city with 350.5 thousand inhabitants and a mechanical waste water treatment plant. The second largest point source input of 5360 tonnes (32.7% of the total point-source load) enters to the Neris river, subcatchment #2 and emanates from the Lithuanian capital Vilnius with 554 thousand inhabitants and from the industrial city Jonava (51.7 thousand inhabitants).

The specific TN contribution to the watercourses from diffuse sources is presented in Table 2.

Table 2. The TN gross load to the watercourses from diffuse sources, kg ha^{-1} yr^{-1}

ID	Arable	Pasture	Forest	Mire	Water
#1	12.0	5.1	1.4	2.2	18.7
#2	18.2	8.7	1.2	1.8	18.7
#3	14.8	6.4	0.8	1.2	18.7
#4	12.4	6.0	1.2	1.9	18.7
#5	17.3	8.3	1.0	1.5	18.7
Mean	15.0	6.9	1.1	1.7	18.7

The highest yearly mean TN load to lakes and rivers comes from deposition – 18.7 kg ha^{-1} yr^{-1}. Arable land adds 15.0 kg ha^{-1} yr^{-1}. The least yearly TN load derives from forests – 1.1 kg ha^{-1} yr^{-1}. The average yearly TN loss from pastures is 6.9 kg ha^{-1} yr^{-1} for the simulated period.

The differences between the TN gross contribution to the River Nemunas subcatchments and the net load in the outlets represent the proportion retained in streams and lakes during the investigated period (Fig. 6).

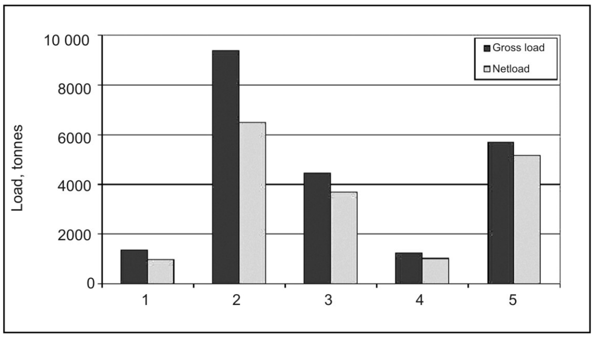

Fig. 6. The TN contribution per subcatchment, before (gross) and after retention (net) within the same subcatchment

The TN retention in the river catchments varies from 9.2 to 30.7% of the total input. The largest proportion, 30.7% of the gross load, is retained in the Neris river, subcatchment #2. The lowest retention 9.2% is in the River Nemunas, subcatchment #5.

3.3. TN export from subcatchments

Using the FyrisNP model, the TN export for 2000–2006 from the River Nemunas catchment to the Baltic Sea was calculated to be 37620 tonnes N yr^{-1}.

Source apportionment for the net load at the outlet of the subcatchments for the entire investigation period is presented in the Table 3.

Table 3. Source apportionment at the outlet of the subcatchments in percent of the total net load

ID	Arable	Pasture	Forest	Mire	Point source	Water
#1	61.0	13.5	15.8	0.5	3.4	5.8
#2	66.0	16.9	4.5	0.2	5.7	6.7
#3	85.1	4.5	2.2	0.1	6.9	1.3
#4	70.4	10.3	15.6	0.3	1.5	1.8
#5	70.3	11.7	4.8	0.1	7.9	5.2

Agricultural load (arable and pasture) varies from 74.5% of the total load in the south-eastern Lithuanian River Merkys (subcatchment #1) outlet to 89.5% in the outlet of the Nevėžis river (subcatchment #3) in the Lithuanian Middle Plain where intensive agriculture dominates. In this basin arable land represents 59.4% of the total catchment area. The TN export from the largest point sources, 7.9% of the total load, is from the River Nemunas (subcatchment #5). The main input enters from Kaunas city with 350.5 thousand inhabitants. The contribution from forest land increases from 2.2% in subcatchment #3 in the Lithuanian Middle Plain, to 15.8% subcatchment #1 in south-eastern part of the country where forest land covers 56.9% of the total catchment area.

3.4. TN load reduction options

Two FyrisNP model scenarios were constructed to evaluate possible measures for reduction of the yearly TN export from Lithuania to the Baltic Sea by 11700 tonnes by 2021, as agreed upon in the new HELCOM Baltic Sea Action Plan (HELCOM 2007). For both scenarios retention coefficients *kvs* and c_o were set the same as for the calibration period.

The first scenario was performed to evaluate the possible decrease in TN export if major waste water treatments plants (WWTP) were modernised according to HELCOM recommendations (HELCOM 2007) in all district cities. After modernisation the TN concentration in effluents after treatment should not exceed the permitted limit of 10 mg l^{-1}. According to this scenario, TN export for 2015–2021 would decrease by 14.4% or 5436 tonnes.

The second model scenario was the conversion of 20% of arable land to pasture, together with the improvements in WWTP. After this, pastures would make up 41% of total agricultural land. This scenario results in reduction of the yearly TN export of 12000 tonnes (31.8%) by 2021. Modelling results show that reduction of point source pollution only is not enough to reach the target. Conversion of 20% of arable land to pasture may not be realistic if agricultural production should remain unchanged or even increase. Some other measures, thus, have to be applied in agricultural land. These could be e.g. increase of winter crop area, intercropping, aftercropping, fertilisation planning according to crop need, spring manure application, etc.). To be able to run this type of scenarios more detailed information on cropping, fertilization, harvests, soil types, etc. are needed than was available for this study.

4. Discussion

4.1. Evaluation statistics

Besides time series charts for observed and modelled concentration and load, the FyrisNP model produces model efficiency (Nash, Sutclife 1970) and correlation coefficient statistics. Thus, the FyrisNP model offers several possibilities to evaluate correspondence between the observed and modelled results. The time series chart of observed and modelled data for the monitoring site #5 of the River Nemunas catchment shows that many of the observed TN peak loads are higher than the modelled ones (Fig. 3). The same pattern exists for time series from the other four subcatchments. In an-other study it was noted that the HBV-N model (Fogelberg *et al.* 2004), which uses a daily time step, could not manage to capture the TN concentration peaks in the Motala and the Ronea rivers (Sweden).

Arvydas Povilaitis (2008) states that absolute values of deviation between the observed and estimated loads constitutes less than 10% from line of equivalence when testing MESAW model for the Merkys river (subcatchment #1). Sofia Fogelberg *et al.* (2004) showed that the relative percentage error between the calculated and observed loads varies from 13.3 to 47% in the Motala and the Ronea catchments (Sweden) for the period of 1993–1999 when using the HBV-N and MONERIS models. Horst Behrendt *et al.* (2005) reported that the mean deviation between the calculated and observed TN loads in the River Odra is 22% and 12% for the dissolved inorganic nitrogen in the River Danube. The calculated model efficiency, correlation coefficient and relative percentage error for the River Nemunas subcatchment #5 for the study period presented in the Table 4.

Table 4. The FyrisNP model efficiency for 2000–2006

ID	River	Model efficiency, E	Correlation coefficient, r	Relative error, %
#1	Merkys	0.7	0.83	11.7
#2	Neris	0.41	0.64	13.2
#3	Nevėžis	0.36	0.61	15.2
#4	Dubysa	0.5	0.71	13.0
#5	Nemunas	0.6	0.78	7.8

These results confirm the reliability of the FyrisNP model outside the catchments where the model has been developed.

4.2. Gross and net loads

Agriculture is commonly pointed out as the main source of nitrogen input to rivers. Ahti Lepisto *et al.* (2006) estimates that in 30 rivers of Finland (60% of the total land area) the diffuse sources (agriculture, forest land and background) conrtibute 74%, deposition 9% and point sources 17% of the total TN input.

N discharges from diffuse sources, point sources and deposition in the River Odra were 68.9, 25.1 and 3.2%, respectively, in the period of 1998–2002 (Behrendt *et al.* 2005). According to the Swedish report on nutrient loads to HELCOM (Brandt *et al.* 2008) the gross contribution from diffuse sources, point sources and deposition in Swedish part of the Baltic Proper sea-basin catchment was 65.6, 22.9 and 11.5%, respectively, in the period of 1985–2004. The proportion of the net load (after retention) is almost the same as that for the gross load. In the River Nemunas catchment contribution from diffuse sources, point sources and deposition for the study period was: 87.3, 7.4 and 5.3%. Consequently, River Nemunas differ from the examples given above due to the high proportion of arable land which causes significant load from diffuse sources. Arable land in the River Nemunas catchment makes up 41.4% of the total catchment area. In Sweden agriculture makes up 19.8% of the Swedish part of the Baltic Proper sea-basin catchment and in Finland – only 8.2% (Lepisto *et al.* 2006).

Different researchers state very similar TN export coefficient from agriculture. Ahti Lepisto *et al.* (2006) used the the N_EXRET model to apply 15.0 kg ha^{-1} yr^{-1} TN gross area specific load in the South-western Finland. Seppo Rekolainen *et al.* (1995) after analysis of 1986–1990 monitoring data in three small agricultural catchments in Finland suggest that TN gross contribution varied from 10.0–22.0 kg ha^{-1} yr^{-1}.

Having analysed the MESAW model results Povilaitis (2008) gives an estimated TN net export coefficient of 14.4 kg ha^{-1} yr^{-1} for the Merkys river (subcatchment #1 in Nemunas River). Our application of the FyrisNP model give an average gross TN export coefficient of 16.2 kg ha^{-1} yr^{-1} for arable land of the entire River Nemunas catchment and net TN export coefficient 12.0 kg ha^{-1} yr^{-1}. Source apportion calculations for the river Susve (main tributary of the Nevėžis river subcatchment #3) gave an export coefficient from agricultural land after retention of 12.6 kg ha^{-1} yr^{-1} (Kronvang *et al.* 2005). Consequently, independent estimates of TN export coefficients for the Nemunas River indicate results within the same size range.

The share of the total TN load coming from atmospheric deposition varies very widely depending mainly on the lake area in the catchment. The contribution from deposition directly on rivers is generally very small. PLC-5[1] calculations in Sweden report that the N load from deposition in the Swedish part of the Baltic Proper sea basin catchment made up 11.5% of the total load (Brandt *et al.* 2008). Horst Behrendt *et al.* (2005) suggest that nitrogen deposition in the River Odra basin for the period of 1998–2002 made up 3.2% of the total load. The TN load from deposition in Lithuania in the study period made up from 1.3 to 6.7% of the total load depending on lake area in the subcatchments. Despite a quite high inputs from deposition in Lithuania (18.7 kg ha^{-1} yr^{-1}) the contribution to the total load is limited due to the small total lake area in the River Nemunas catchment.

The mean area TN specific gross load from all sources of pollution in the whole River Nemunas catchment is estimated to be 9.6 kg ha^{-1} yr^{-1} for the period of 2000–2006. Beherndt *et al.* (2005a, b), using MONERIS model, reported a TN gross load of 8.9 kg ha^{-1} yr^{-1} for 1998–2002 in the River Odra catchment and 9.4 kg ha^{-1} yr^{-1} for the year 2000 in the River Danube catchment. Lepisto *et al.* (2006) calculated a TN gross load of 5.9 kg ha^{-1} yr^{-1} in 30 Finish catchments. Brandt *et al.* (2008) delivered a TN gross load of 5.1 kg ha^{-1} yr^{-1} to the Swedish part of the Baltic Proper sea basin catchment.

Some investigators present only the value of the area specific export coefficient (net load). Stalnacke *et al.* (1996) reported 6.1 kg ha^{-1} yr^{-1} as an average area-specific export of the TN to the Baltic Proper sea sub basin from the River Vistula in the period of 1980–1993. The area-specific export of TN form the River Elbe was calculated to 7.4 kg ha^{-1} yr^{-1} in 1998–2000 (Hussian *et al.* 2003).

If the TN retention in streams is assumed to be no higher than 20%, the gross load can be estimated to be maximum 7.3 and 8.9 kg ha^{-1} yr^{-1} in the Vistula and the Elbe rivers, respectively. Hence, comparison of the total gross TN loads in the catchments of various European large rivers shows that the area-specific load in the River Nemunas catchment is the highest one.

Previous studies (Sileika *et al.* 2006) have revealed an increase of flow normalised area-specific load of nitrate (NO_3–N) from 1986 to 2000 at almost all the sampling sites in the River Nemunas and its tributaries. These results give evidence that dramatic changes in agricultural production in former Soviet Lithuania have increased NO_3–N loads in the River Nemunas. Changes in land use and extensive ploughing of pastures could have enhanced mineralisation of organic nitrogen and significantly increased the NO_3–N losses to rivers in the catchment. The same trends have been observed in other former Soviet countries (Stalnacke *et al.* 1999b; Klavins *et al.* 2001; Jansons *et al.* 2002; Iital *et al.* 2010). NO_3–N represents a large proportion of TN concentration. Therefore, it can be expected that the TN discharges have also increased.

4.3. Retention

Nutrient gross loads from various pollution sources in the studied catchments almost always exceed the load leaving the catchments. The difference is generally called retention (Harrison *et al.* 2009; Hejzlar *et al.* 2009; Saunders, Kalff 2001). Nitrogen retention is mainly caused by denitrification and sedimentation. Retention is difficult to measure, but it can be estimated using catchment mass balance models (Molot, Dillon 1993; Windolf *et al.* 1996). Various pathways are used for retention calculations in models. The MONERIS model calculates retention on land, in soil, groundwater and in the river systems (Behrendt *et al.* 2005), while the HBV-N model calculates retention in groundwater, streams and lakes (Fogelberg 2003). The MESAW model (Povilaitis 2008) takes into account the total area of the catchment and the N_EXRET model evaluates retention in peat lands and lakes (Lepisto *et al.* 2006). The FyrisNP model simulates retention in rivers and lakes and can incorporate a separate lake module for larger lakes situated close to the subcatchment outlet (Hansson 2008b). Due to different N input, land use and lake areas the estimated retention differs significantly. For example, for the Merkys river subcatchment #1 Povilaitis (2008) reported that 60% of the total TN load is retained before the outlet, while the FyrisNP model simulates 26% retention for the same subcatchment. Having used the EUROHARP-NUTRET tool for retention calculation Kronvang *et al.* (2005) estimated that 13.4% of the TN is retained in the Susve river (main tributary of the Nevėžis river #3), while the FyrisNP model computes 19.3%. Lepisto *et al.* (2006) estimate average total retention (retention in lakes and

[1] PLC-5 HELCOM‘s fifth Pollution Load Compilation (HELCOM 2011)

peat lands) of 35% for 30 Finish rivers. Having compared retention in two Swedish and two German river catchments Fogelberg (2003) states that there were minimal differences between HBV-N and MONERIS predictions in two of the catchments. However, in other two catchments HBV-N, calculated much lower retention than MONERIS. Retention value depends on the calculation method and N flow pathway assumption, as well as catchment characteristics Kronvang *et al.* (2005). TN retention in FyrisNP depends on many factors but mainly on hydraulic load (Table 5).

Table 5. Hydraulic load and TN retention in the River Nemunas subcatchments

ID	River	Hydraulic load, m yr^{-1}	Retention, % of the total load
#1	Merkys	10.72	26.0
#2	Neris	5.55	30.7
#3	Nevėžis	17.33	17.0
#4	Dubysa	24.84	15.8
#5	Nemunas (excluding tributaries and upper reaches in Belarus)	4.42	9.2

The highest retention (30.7%) was calculated for the Neris River (subcatchment #2) due to low hydraulic load (5.55 m yr^{-1}). Retention in Dubysa river (subcatchment #4) with the highest hydraulic load (24.84 m yr^{-1}) was low – 15.8%. The River Nemunas (subcatchment #5) has the lowest retention (9.2%) of gross TN load despite the lowest hydraulic load (4.42%). It can be because the biggest polluters (Kaunas city and the Nevėžis river outlet) are close to the subcatchment outlet.

Conclusions

1. Agricultural net load varies from 74.6 to 89.5% of the total nitrogen net load depending on the percentage of arable land and the load from point sources in five subcatchments of the River Nemunas. The main input from point sources enters at Kaunas city with poor waste water treatment. Contribution from forest land varies from 2.2% to 15.8% with increasing percentage forest land from 28.5 to 56.9% of the total area of subcatchments. The highest retention of N (30.7%) is observed in the river subcatchment with the lowest hydraulic load (5.55 m yr^{-1}).

2. Scenario modelling suggests that the Lithuanian reduction target of 11,700 tonnes nitrogen by 2021 to the Baltic Sea can be achieved after installation of biological treatment in all district cities and implementation of measures to reduce the TN load in agriculture. By modernisation of waste water treatment plants in all district cities the yearly TN export would decrease by 14.4% or 5436 tonnes. Conversion of 20% of arable land to pasture (or implementation of other equivalent measures in agriculture) together with the improvements in WWTP would give reduction of the TN yearly export of 12,000 tonnes (31.8%).

3. Assessment of the FyrisNP model results shows that the model can be successfully applied for the river basin management planning in catchments outside of the area where the model has been developed.

4. The aggregated target in the national water management plan (reduction of TN load to the Baltic Sea 11 700 tonnes by 2021) should be complemented with a specific reduction target focusing on the main sources of pollution from – agriculture and point sources.

Acknowledgements

This work has been performed within the Harmo Balt Project included in the SIDA/GEF/Worldbank funded Baltic Sea Regional Project. We would like to thank all the persons from the Department of Aquatic Science and Assessment, Swedish University of Agricultural Sciences for introducing us to the FyrisNP model. Special thanks to Klas Hansson and Faruk Djodjic for helping us with the application of the model to the River Nemunas catchment and for valuable comments on the manuscript.

References

Anon 2000. *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive)* [online], [cited 23 February 2012]. Available from Internet: http://ec.europa.eu/environment/water/water-framework/index_en.html

Anon 1994. Lietuvos aplinkos ministerija 1994. *Unifikuoti nuotekų ir paviršinių vandenų kokybės tyrimų metodai* [Unified methods for water quality analyses of effluents and surfrace waters]. Vilnius, 9–22 (in Lithuanian).

Anon 2008. Directive 2008/56/EC the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), *Official Journal of the European Union* 164: 19–40.

Bagdžiūnaitė-Litvinaitienė, L. 2004. Dynamics of nutrient changes in the water of SE Lithuanian Rivers for different periods of water level, *Journal of Environmental Engineering and Landscape Management* 12(4): 146–152.

Behrendt, H.; Opitz, D.; Korol, R.; Stronska, M. 2005. Changes of the nutrient loads of the Odra River during the last century – their causes, in *Proceedings ICID Conference,* 15–19 May 2005, Frankfurt (Oder), (CD).

Brandt, M.; Ejhed, H.; Rapp, L. 2008. *Nutrient loads to the Swedish marine environment in 2006.* Sweden's report for HELCOM's fifth pollution load compilation. Stockholm: Swedish Environmental Protection Agency.

Euroharp 2003. *Review and literature evaluation of quantification tools for the assessment of nutrient losses at catchment scale.* EUROHARP Report 1-2003, Wageningen: ALTERRA.

Fogelberg, S.; Arheimer, B.; Venohr, M.; Behrendt, H. 2004. Catchment modelling of nitrogen flow with two different conceptual models, in *Proceedings of Nordic Hydrologic Conference,* 2004, Tallin, 48: 149–158.

Fogelberg, S. 2003. *Modelling nitrogen retention at the catchment scale*. Report UPTEC W 03 019. Uppsala: Uppsala Universitet, 1–51.

Gailiusis, B.; Jablonskis, J.; Kovalenkoviene, M. 2001. *Lietuvos upės. Hidrografija ir nuotėkis* [Lithuanian rivers. Hydrography and runoff]. Kaunas: Energetikos institutas, 136–139 (in Lithuanian).

Grizzetti, B.; Bouraoui, F.; Marsily, G.; Bidoglio, G. 2005. A statistical method for source apportionment of riverine nitrogen loads, *Journal of Hydrology* 304: 302–315. http://dx.doi.org/10.1016/j.jhydrol.2004.07.036

Hansson, K.; Wallin, M.; Djodjic, F.; Orback, K. 2008a. *The FYRIS model Version 3.1. A tool for catchment-scale modelling of source apportioned gross and net transport of nitrogen and phosphorus in rivers.* A user´s manual, Version 3.1. Uppsala: Swedish University of Agricultural Sciences 18: 6–28.

Hansson, K.; Wallin, M.; Djodjic, F.; Orback, K. 2008b. *The FYRIS model Version 3.1. A tool for catchment-scale modelling of source apportioned gross and net transport of nitrogen and phosphorus in rivers.* Technical description, Version 3.1. Uppsala: Swedish University of Agricultural Sciences 19: 6–17.

Harrison, L. A.; Maranger, R. J.; Alexander, R. B.; Giblin, A. E.; Jacinte, P.-A.; Mayorhga, E.; Seitzinger, S. P.; Sobota, D. J.; Wollheim, W. M. 2009. The regional and global significance of nitrogen removal in lakes and reservoirs, *Biogeochemistry* 93: 143–157. http://dx.doi.org/10.1007/s10533-008-9272-x

Hejzlar, J.; Anthony, S.; Arheimer, B.; Behrendt, H.; Bouraoui, F.; Grizetti, B.; Groenendijk, P.; Jeiken, M. H. J. L.; Johnsson, H.; Lo Porto, A.; Kronvang, B.; Panagopoulos, Y.; Siderius, C.; Silgram, M.; Venohr, M.; Zaloudik, J. 2009. Nitrogen and phosphorus retention in surface waters: an inter-comparison of predictions by catchment models of different complexity, *Journal of Environmental Monitoring* 11: 584–593. http://dx.doi.org/10.1039/b901207a

HELCOM 2011. *The fifth Baltic Sea pollution load compilation (PLC-5)* [online], [cited 23 February 2012]. Available from Internet: www.helcom.fi/stc/files/Publications/ Proceedings/BSEP128.pdf, 2011.

HELCOM 2007. *HELCOM Baltic Sea action plan* [online]. Adopted on 15 November 2007 in Krakow, Poland by the HELCOM Extraordinary Ministerial Meeting [cited 23 February 2012]. Available from Internet: http://www.helcom.fi/stc/files/BSAP/BSAP_Final.pdf

HELCOM 2008. *HELCOM activities 2008 overview*. Helsinki, 19–20.

Hussian, M.; Grimvall, A.; Petersen, W. 2003. Estimation of the human impact on nutrient loads carried by the Elbe River, *Environmental Monitoring and Assessment* 96: 15–33. http://dx.doi.org/10.1023/B:EMAS.0000031722.88972.62

Iital, A.; Pachel, K.; Loigu, E.; Pihlak, M.; Leisk, U. 2010. Recent trends in nutrient concentrations in Estonian rivers as a response to large-scale changes in land-use intensity and life-styles, *Journal of Environmental Monitoring* 12: 178–188. http://dx.doi.org/10.1039/b912923e

Jansons, V.; Vagstad, N.; Sudars, R.; Deelstra, J.; Dzalbe, I.; Kirsteina, D. 2002. Nutrient losses from point and diffuse agricultural sources in Latvia, *Landbauforsch Volkenrode* 1(52): 9–17.

Johnes, P. J.; Burt, T. P. 1993. Nitrate in surface waters, in Burt, T. P., *et al.* (Eds.). *Nitrate: Processes, Patterns and Management*. Chichester, 269–317.

Keeney, D. R.; DeLuca, T. H. 1993. Des Moines River nitrate in relation to watershed agricultural practices: 1945 versus 1980's, *Journal of Environmental Quality* 20: 123–128.

Klavins, M.; Rodionov, V.; Kokorite, I.; Klavina, I.; Apsite, E. 2001. Long-term and seasonal changes in chemical composition of surface waters in Latvia, *Environmental Monitoring and Assessment* 66: 233–251. http://dx.doi.org/10.1023/A:1006352015230

Kronvang, B.; Hezlar, J.; Boers, P.; Jensen, J. P.; Behrendt, H.; Anderson, T.; Arheimer, B.; Venohr, M.; Hoffmann, C. C. 2004. *Nutrient Retention Handbook,* EUROHARP Report 9-2004. Norway: NIVA.

Kronvang, B.; Larsen, S. E.; Jensen, J. P.; Andersen, H. E.; Sileika, A. S. Gaigalis, K. 2005. *Susve, Lithuania. Trend analysis Retention and Source Apportionment*, EUROHARP Report 12-2005. Denmark: NERI.

Lepisto, A.; Granlund, K.; Kortelainen, P.; Raike, A. 2006. Nitrogen in river basins: sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland, *Science of the Total Environment* 365: 238–259. http://dx.doi.org/10.1016/j.scitotenv.2006.02.053

Lindgren, G. A.; Wrede, S.; Seibert, J.; Wallin, M. 2007. Nitrogen source apportionment modeling and the effect of land-use class related runoff contributions, *Nordic Hydrology* 38: 317–331. http://dx.doi.org/10.2166/nh.2007.015

Magner, J.; Payne, G.; Steffen, L. 2004. Drainage effects on stream nitrate-N and hydrology in south-central Minnesota (USA), *Environmental Monitoring and Assessment* 91: 183–198. http://dx.doi.org/10.1023/B:EMAS.0000009235.50413.42

Molot, L. A.; Dillon, P. 1993. Nitrogen mass balances and denitrification rates in central Ontario Lakes, *Biogeochemistry* 20: 195–212. http://dx.doi.org/10.1007/BF00000787

Nash, J. E.; Sutcliffe, J. V. 1970. River flow forecasting through conceptual models part I – a discussion of principles, *Journal of Hydrology* 10 (3): 282–290. http://dx.doi.org/10.1016/0022-1694(70)90255-6

National Land Service 2004. *Topographic information LTDBK50000-V*. Vilnius (in Lithuanian).

Nixon, S. W.; Ammerman, J. W.; Atkinson, L. P.; Berounsky, V. M.; Billen, G.; Boicourt, W. C.; Boynton, W. R.; Church, T. M.; Ditoro, D. M.; Elmgren, R.; Garber, J. H.; Giblin, A. E.; Jahnke, R. A.; Owens, N. J. P.; Pilson, M. E. Q.; Seitzinger, S. E. 1996. The fate of nitrogen and phosphorus at the land-sea margin of the North Atlantic Ocean, *Biogeochemistry* 35: 141–180. http://dx.doi.org/10.1007/BF02179826

Poluckaja, N. 2000. *Neman* [Nemunas]. Byelorussia: Grodno, 4–5.

Povilaitis, A. 2008. Source apportionment and retention of nutrients and organic matter in the Merkys River basin in southern Lithuania, *Journal of Environmental Engineering and Landscape Management* 16(4): 195–204. http://dx.doi.org/10.3846/1648-6897.2008.16.195-204

Rekolainen, S. 1989. Phosphorus and nitrogen load from forest and agricultural areas in Finland, *Aqua Fennica* 19(2): 95–107.

Rekolainen, S.; Pitkanen, H.; Bleeker, A.; Felix, S. 1995. Nitrogen and Phosphorus fluxes from Finnish agricultural areas to the Baltic Sea, *Nordic Hydrology* 26: 55–72.

Saunders, D. L.; Kalff, J. 2001. Nitrogen retention in wetlands, lakes and rivers, *Hydrobiologia* 443: 205–212. http://dx.doi.org/10.1023/A:1017506914063

Sileika, A. S.; Gaigalis, K.; Kutra, G.; Smitiene, A. 2005. Factors affecting N and P losses from small catchments (Lithuania), *Environmental Monitoring and Assessment* 102(1–3): 359–374. http://dx.doi.org/10.1007/s10661-005-6033-3

Sileika, A. S.; Stalnacke, P.; Kutra, S.; Gaigalis, K.; Berankiene, L. 2006. Temporal and spatial variation of nutrient levels in the Nemunas River (Lithuania and Belarus), *Environmental Monitoring and Assessment* 122: 335–354. http://dx.doi.org/10.1007/s10661-006-9186-9

Šileika, A. S.; Gaigalis, K.; Šmitiene, A.; Baigys, G. 2010. Impact of some environmental and agricultural factors on nitrogen loss in three Lithuanian catchments, *Vandens ūkio inžinerija* [Water Management Engineering] 37(57): 52–63.

Stalnacke, P.; Grimvall, A.; Laznik, M. 1996. Water quality response to the dramatic reduction in the use of fertilizers in Latvia, in *Nutrient Loads to the Baltic Sea:* PhD Thesis. Linkoping: Linkoping University. 1–14.

Stalnacke, P.; Grimvall, A.; Sundblad, K.; Wilander, A. 1999a. Trends in nitrogen transport in Swedish rivers, *Environmental Monitoring and Assessment* 59: 47–72. http://dx.doi.org/10.1023/A:1006007711735

Stalnacke, P.; Grimvall, A.; Sundblad, K.; Tonderski, A. 1999b. Estimation of Riverine Loads of Nitrogen and Phosphorus to the Baltic Sea, 1970–1993, *Environmental Monitoring and Assessment* 58: 173–200. http://dx.doi.org/10.1023/A:1006073015871

SWAT 2005. *Soil and water assessment tool SWAT 2005* [online], [cited 05 March 2005]. Available from internet: http://swatmodel.tamu.edu.

Vaitkuviene, D.; Dagys, M. 2008. CORINE 2006 *land cover, Lithuania.* Implementing CLC2006 project in Lithuania, Report. Vilnius: Institute of Ecology of Vilnius University (in Lithuanian).

Windolf, J.; Jeppesen, E.; Jensen, J. P.; Kristensen, P. 1996. Modelling of seasonal variation in nitrogen retention and in-lake concentration: a four year mass balance study in 16 shallow Danish lakes, *Biogeochemistry* 33: 25–44. http://dx.doi.org/10.1007/BF00000968

Vitousek, P.; Moony, H.; Lubchenco, J.; Melillo, J. 2004. Human domination of Earth's ecosystems, *Science* 277: 494–499. http://dx.doi.org/10.1126/science.277.5325.494

Vuorenmaa, S.; Rekolainen, S.; Lepisto, A.; Kenttamies, K.; Kauppila, P. 2002. Losses of nitrogen and phosphorus from agricultural and forest areas in Finland during the 1980s and 1990s, *Environmental Monitoring and Assessment* 76: 213–248. http://dx.doi.org/10.1023/A:1015584014417

Vuoristo, H. 1998. Water quality classification of Finnish inland waters, *Eur. Water. Manag*. 6: 35–41.

Wulf, F.; Rahm, L. 1988. Long-term, seasonal and spatial variations of nitrogen, phosphorus and silicate in the Baltic: an overview, *Marine Environmental Research* 26: 19–37. http://dx.doi.org/10.1016/0141-1136(88)90032-3

Antanas Sigitas ŠILEIKA. Dr, chief researcher, Water Research Institute of the Aleksandras Stulginskis University. Research interest: Surface water quality modelling, assessment and search of measures for pollution reduction.

Mats WALLIN. PhD, director, Department of Aquatic Science and Assessment, Swedish University of Agricultural Sciences Research interest: Catchment scale water quality modelling and assessment of the impact of point source and non-point source pollution on rivers and lakes.

Kazimieras GAIGALIS. Dr, senior researcher, Water Research Institute of the Aleksandras Stulginskis University. Research interest: Hydrology, water flow and quality monitoring.