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WATER QUALITY MODELING IN BĒRZE RIVER CATCHMENT

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Abstract. The paper describes water quality modeling approaches for the mid-sized river (100–1000 km^2) catchment in Latvia. The hydro-chemical data (2005 to 2010) in 15 subcatchments of Bērze River (872 km^2) represent water quality and land use type-specific concentrations. Water sampling shows that significant pollution results from management of organic manure and intensive agriculture, where the maximum concentrations of nitrate nitrogen are 9.2 and 18.1 mg l^{-1} reaching or exceeding the limit established by the EU Nitrates Directive of 11.3 mg l^{-1}. The application of pollution load source apportionment could be useful for decision making to set up the action plans for the implementation of appropriate pollution reduction measures.

Keywords: type-specific concentration, nutrients, source apportionment, retention.

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Introduction

Nutrient leakage models have not been applied in Latvia in order to estimate water quality and pollution source apportionment. Therefore, in co-operation with the Swedish University of Agricultural Sciences (personal conversation with M. Wallin, A. Gustafson, M. Larsson) water quality monitoring and modeling framework was developed for Bērze River (Fig. 1). To establish an empirical link between river headwaters and main stem of the river (Smith 2003), a multiscale monitoring approach was proposed.

This included water quality and load measurements at three different monitoring scales, i.e. drainage field, small catchment and medium sized river. These measurements are already being carried out as part of the proposed catchment measurement program (Kyllmar *et al.* 2006) and partly through the state financed monitoring programs.

Additional data are collected in connection with reporting to the EU Nitrates Directive. Simulation results are used to identify this river's catchment specific nutrients (nitrogen and phosphorus) pollution load distribution (Povilaitis 2008), and retention rates (Kneis *et al.* 2006). This could be useful for water protection measures regarding the EU Water Framework Directive river basin management approach.

1. Materials and methods

The Bērze River catchment (Fig. 1) was selected as the study area for water quality modeling in Latvia. The Bērze River is a part of Lielupe River basin district that is one of four river basin districts designated according to the Water Framework Directive.

Most of the Bērze River is located within vulnerable zones according to the EU Nitrates Directive.

Starting the year 2005 water samples at 15 Bērze River subcatchments were collected on monthly and seasonal basis (Fig. 1), to characterize the water quality (Vadas *et al.* 2007) of river stages (Subcatchment ID 2, 3, 6, 9, 12, 15), major tributaries (ID 4, 8, 10, 13, 14) and various types of land use impacts, e.g. agriculture (ID 14.) tile drained area (No. 15), Dobele city (ID 12), forest (ID 10, 11), lake (ID 5) and peat bog (ID 1), Annenieku hydro-power plant (ID 6), management of organic manure from animal husbandry (ID 7).

To emphasize the modeling period, additionally, two time series (2000–2005) both for total nitrogen and phosphorus concentrations before and after Dobele city were added from Latvian Environment, Geology and Meteorology Centre (LEGMC) monitoring. One meteorological station Dobele is located within Bērze River catchment.

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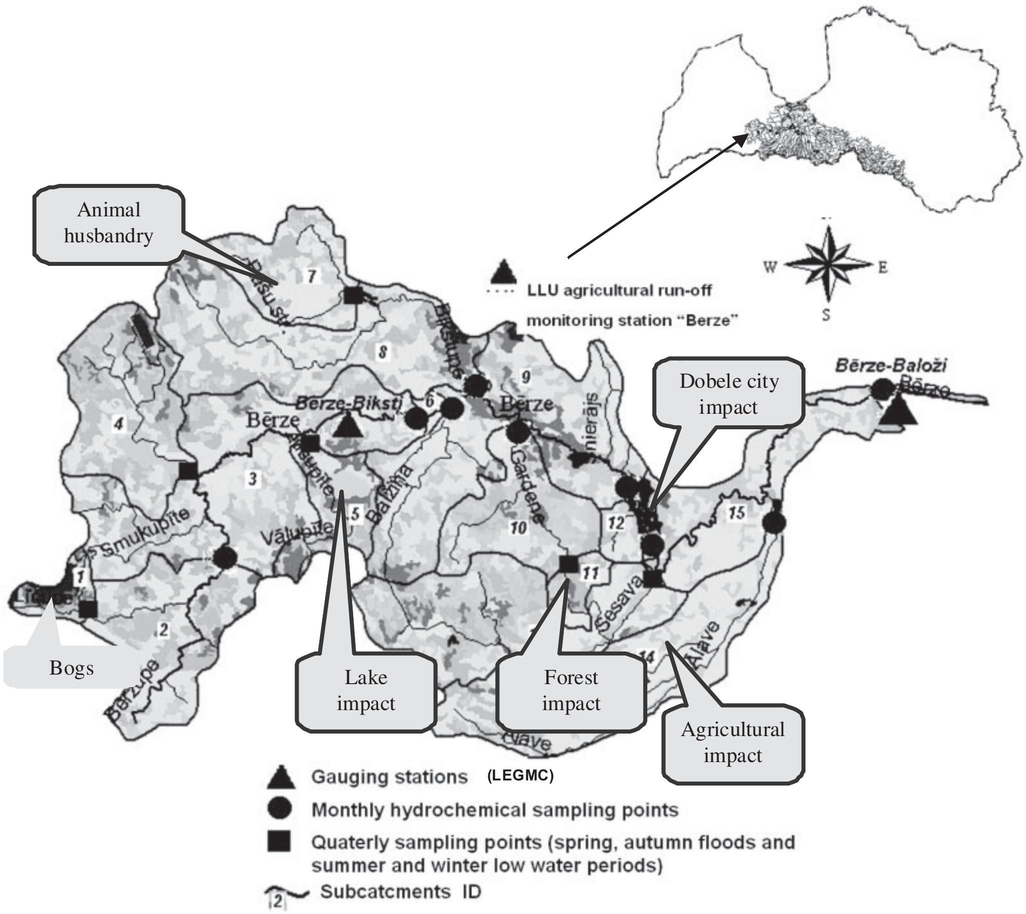

Fig. 1. Location of Bērze River and water quality monitoring network

There are available data for 2 LEGMC hydrological gauging stations Bērze-Baloži and Bērze-Biksti with daily discharge measurements since 1951 (Table 1). Unfortunately, nowadays station Bērze-Biksti is closed, but still existing data sets are available for model calibration of this catchment.

Long-term agricultural run-off monitoring data (1994–2010) collected by Latvia University of Agriculture (LLU) in the monitoring station "Bērze" including measurements in small agricultural catchment (3.68 km^2) and drainage field (76.6 ha) are representative for agricultural production levels and trends (Klavins *et al.* 2001; Klavins, Kokorite 2002) as well as type-specific concentrations for arable land.

2. Description of study area

Bērze River is situated at the central part of Latvia and is the tributary of Svēte River that inflows into Lielupe River and then into Gulf of Riga. The length of the Bērze is 109 km (slope 108 m per 109 km) and the river catchment covers an area of ~872 km^2.

Bērze River starts in drained meadows in Southern part of Eastern-Courland highland (~120 m above the sea level) with slightly hilly surroundings and steep banks. In the middle part of basin there is a hydro-power plant "Annenieki" with reservoir that could influence nutrient retention.

Then Bērze flows through Dobele city. In the downstream part of Bērze River (land level ~10 m

Table 1. Main characteristics of Bērze River hydrology

River	Gauging station	Observation period	Area km^2	Average Q, m^{3}s^{-1}	Average q, l s^{-1}km^2	$Q_{max,\ 1\%}$, m^{3}s^{-1}	$Q_{30days\ min.,\ 95\%}$ summer	$Q_{30days\ min.,\ 95\%}$ winter
Bērze	Baloži	1951–2010	872	5.04	8.06	92.6	1.21	2.65
Bērze	Biksti	1951–1994	275	2.46	8.10	41.8	0.65	1.40

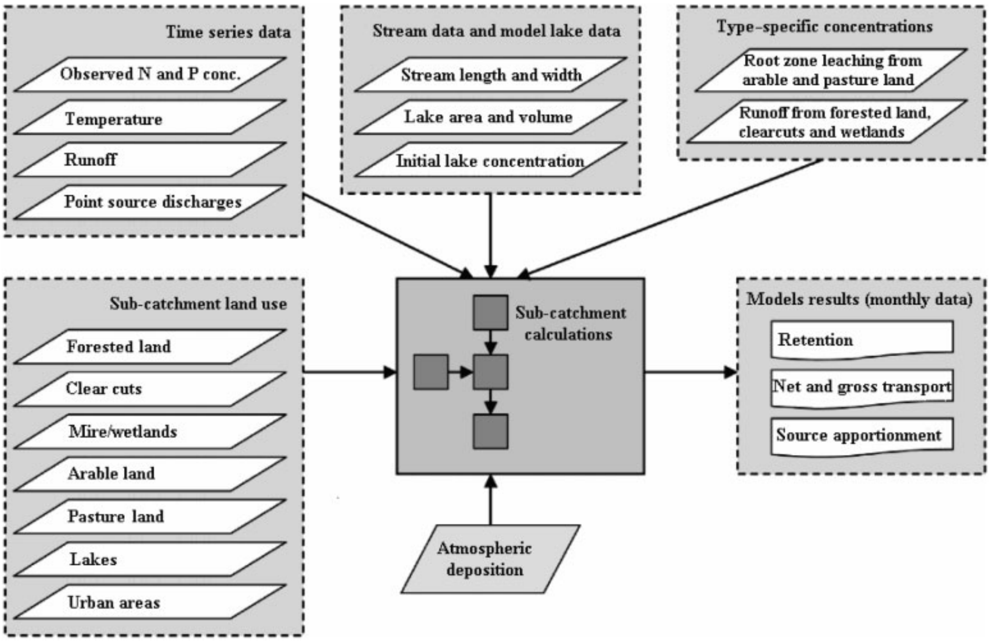

Fig. 2. Structure of FyrisNP model inputs and outputs (Hansson *et al.* 2008)

above the sea level) large sub-surface drainage systems are constructed.

Last 6.5 km before the inlet into Svēte River the riverbed of Bērze is straightened and dams system of polder separates river from surrounded drainage area. Middle and downstream part of Bērze River catchment is typical for Zemgale region plains with highly intensive agricultural land in the catchment. Normal year water balance: precipitation 630 mm, run-off 200 mm and evaporation 430 mm (Table 1).

3. Model description

The dynamic FyrisNP model calculates source apportioned gross and net transport of nitrogen and phosphorus in rivers and lakes (Hansson *et al.* 2008). The main scope of the FyrisNP model (Fig. 2) is to assess the effects of different nutrient reduction measures on the catchment scale. The time step for the model is in the majority of applications one month and the spatial resolution is on the sub-catchment level.

Table 2. Land use in Bērze River subcatchments (CLC 2000)

Subcatchment ID	Arable land (km^2)	Pasture (km^2)	Mixed agricultural land (km^2)	Forest (km^2)	Clearcuts (km^2)	Urban areas (km^2)	Lake area (km2)	Stream area (km^2)	Mire, wetlands (km^2)	Total area (km^2)
1	0.41	0.11	0.24	4.82	0.15	–	0.03	0.00	3.57	9.32
2	9.21	8.91	11.19	38.45	1.19	–	0.18	0.15	–	69.28
3	22.97	21.05	15.65	58.34	1.80	–	0.62	0.45	0.27	121.16
4	5.67	7.29	4.19	37.14	1.15	–	0.37	0.07	1.35	57.22
5	1.11	3.11	2.15	15.88	0.49	–	4.81	0.01	0.34	27.90
6	2.21	1.00	0.27	0.38	0.01	–	0.27	0.04	–	4.19
7	14.58	6.85	3.04	17.88	0.55	0.03	0.15	0.08	–	43.16
8	32.13	12.44	7.57	44.71	1.38	0.63	0.45	0.19	1.44	100.94
9	28.40	12.38	14.14	46.30	1.43	0.91	1.02	0.32	0.69	105.59
10	6.11	4.64	8.90	30.40	0.94	–	1.35	0.06	0.59	53.00
11	2.78	0.29	1.67	15.39	0.48	–	–	0.01	–	20.62
12	1.71	1.58	2.22	2.54	0.08	4.25	0.10	0.33	–	12.81
13	20.18	4.95	11.75	49.75	1.54	–	0.79	0.10	0.42	89.49
14	53.90	5.02	11.43	21.59	0.67	0.46	0.46	0.14	–	93.68
15	26.49	7.22	17.63	10.23	0.32	1.03	0.03	0.74	–	63.69
Total in basin	227.85	96.85	112.04	393.81	12.18	7.31	10.64	2.70	8.67	872.05
Proportion, %	26.13	11.11	12.85	45.16	1.40	0.84	1.22	0.31	0.99	100

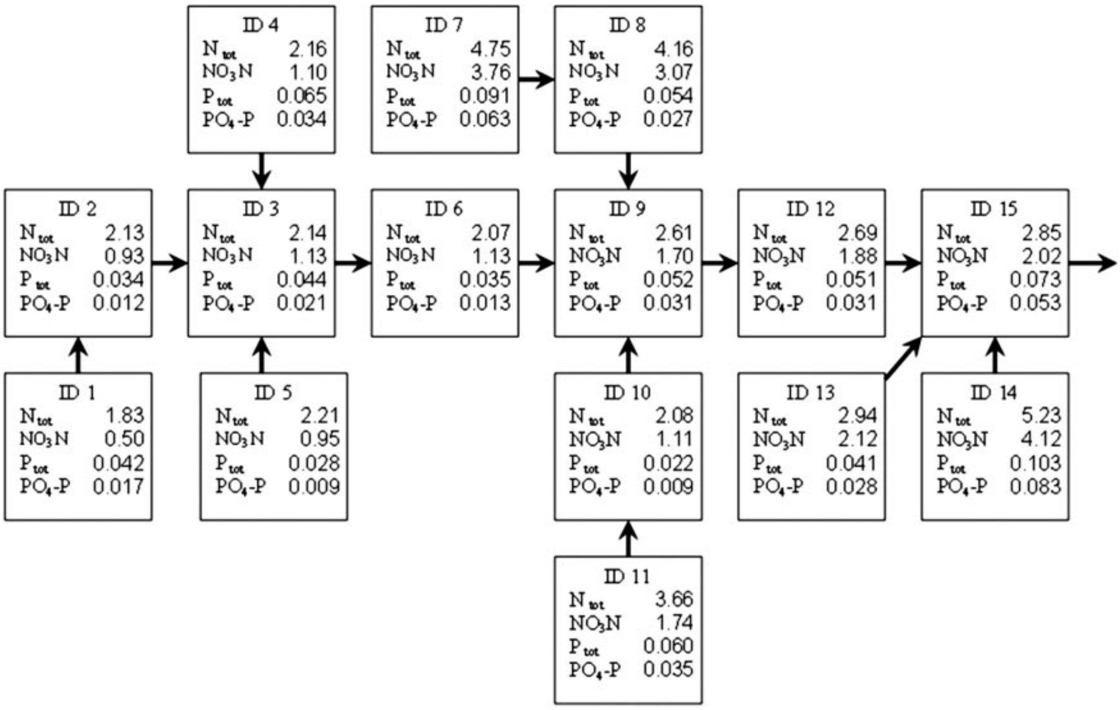

Fig. 3. Average N and P concentrations [mg l^{-1}] in Bērze River subcatchments (2005–2010)

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 nitrogen concentration and lake area, and stream area. The model is calibrated with regard to two retention parameters, k_{vs} (retention parameter, m/year) and c0 (temperature parameter, dimension less), using time series on measured nitrogen and phosphorus concentrations in subcatchments (Hansson *et al.* 2008). In order to evaluate the fit of simulated to measured values the model efficiency E, and the correlation coefficient r are used.

The definition of the FyrisNP model efficiency:

$$E = 1 - \frac{\sum_{i=1}^{n}\left(\Theta_{obs,i} - \Theta_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(\Theta_{obs,i} - \bar{\Theta}_{obs}\right)^2},$$

where: n is the number of observations, and $\bar{\Theta}_{obs}$ is the mean value of all observations. The Θ symbolizes whatever time-series are compared. In the FyrisNP model, Θ_{obs} and Θ_{sim} are the observed and modelled concentrations, respectively.

Data used for calibrating and running the FyrisNP (Hansson *et al.* 2008) model can be divided into

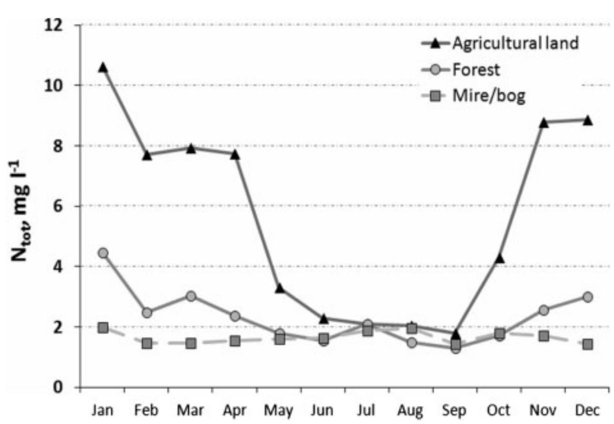

Fig. 4. Total nitrogen type-specific concentrations for diffuse source pollution

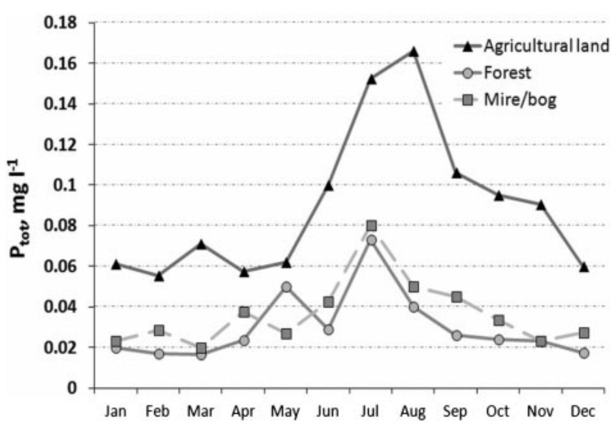

Fig. 5. Total phosphorus type-specific concentrations for diffuse source pollution

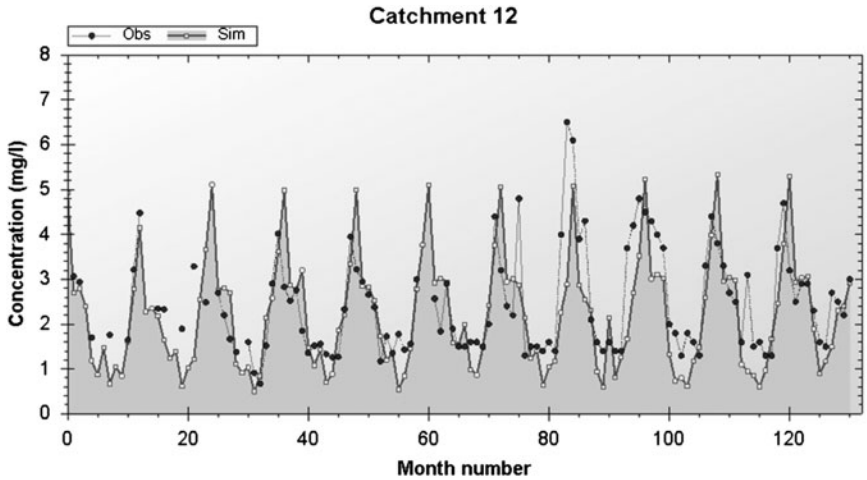

Fig. 6. Modeled and observed total nitrogen concentrations in FyrisNP model

time-dependent data, e.g. time series on observed nitrogen and phosphorus concentration, water temperature, runoff and point source discharges, and time-independent data, e.g. land-use information (Table 2) according to CORINE Land Cover 2000 (CLC 2000), lake area and stream length and width.

4. Results and discussion

The conceptual FyrisNP model (Hansson *et al.* 2008) was chosen to identify the impact of the sources of pollution with total nitrogen (N) and phosphorus (P) in the Bērze River. The modeling encompasses the time period from 2000–2010. There is relatively high mire (ID 1) and the forest (ID 10) background N_{tot} average concentrations, 1.83 and 2.08 mg l^{-1}, respectively, but nitrate nitrogen concentrations in these subcatchments (0.50 and 1.11 mg l^{-1}) are among the lowest in Bērze River catchment (Fig. 3).

Observed water quality data (Fig. 3) show significant differences between average concentrations (Vuorenma *et al.* 2002) of natural background (bogs, forests) and anthropogenic impacted areas (Dobele city and agricultural land). It was also found that NO_3–N ratio against N_{tot} is higher in agricultural lands (70–85%) compared to forests (~53%) or bogs (27%). Similar ratios are typical also for PO_4-P against P_{tot}, i.e. agricultural lands (70%–81%), forests (45–55%) or bogs (40%).

One of the FyrisNP model tasks is to determine the type-specific pollution concentrations for load calculations. For this purpose, in Bērze River, subcatchments were preselected with significant mire (bogs), forest and agricultural land share information on diffuse pollution concentrations (Stålnacke *et al.* 2003). Seasonal fluctuation of total nitrogen concentrations shows higher values during winter and spring periods (Fig. 4) whereas total phosphorus concentra-

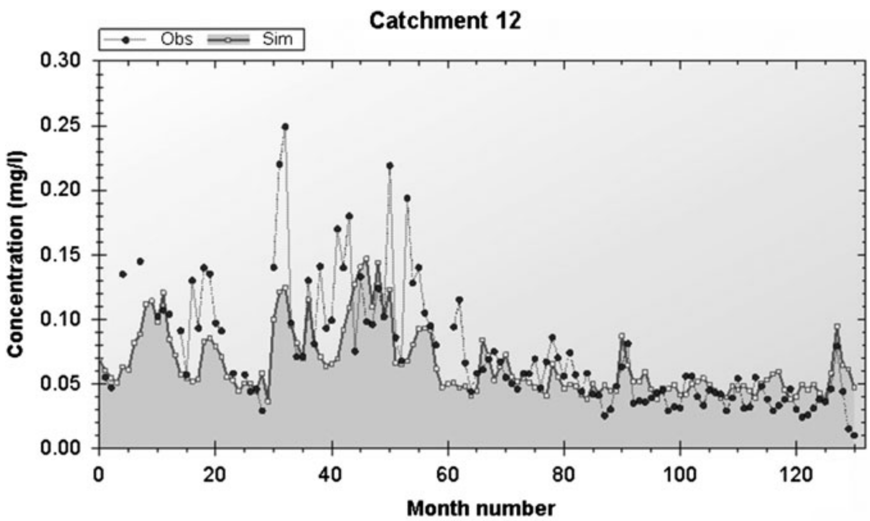

Fig. 7. Modeled and observed total phosphorus concentrations in FyrisNP model

Table 3. Pollution load and retention in Bērze River subcatchments (2000–2010)

Subcatchment ID	Total Nitrogen Gross contribution (kg)	Total Nitrogen Net contribution (kg)	Total Nitrogen Load kg ha^{-1} year	Total Nitrogen Mean retention %	Total Phosphorus Gross contribution (kg)	Total Phosphorus Net contribution (kg)	Total Phosphorus Load kg ha^{-1} year	Total Phosphorus Mean retention %
1	50562	44104	4.93	12.8	1015	726	0.10	28.5
2	492138	419035	6.46	14.9	5538	3880	0.07	29.9
3	922488	801997	6.92	13.1	16373	11807	0.12	27.9
4	381253	299550	6.06	21.4	9857	6061	0.16	38.5
5	176065	103409	5.74	41.3	2726	842	0.09	69.1
6	46313	44285	10.05	4.4	981	889	0.21	9.3
7	410500	339296	8.65	17.3	5949	4115	0.13	30.8
8	881331	750963	7.94	14.8	20725	15540	0.19	25.0
9	880060	809197	7.58	8.1	17119	14363	0.15	16.1
10	363109	247584	6.23	31.8	5808	2103	0.10	63.8
11	142165	136998	6.27	3.6	2431	2204	0.11	9.4
12	160041	155436	11.36	2.9	24845	23042	1.76	7.3
13	698509	531515	7.10	23.9	12196	6800	0.12	44.2
14	1059232	859919	10.28	18.8	21990	14042	0.21	36.1
15	646733	623024	9.23	3.7	22259	20282	0.32	8.9

tions are high in summer period compared to winter season (Fig. 5).

There are no mountains in Bērze River catchment and thus it was possible to improve the FyrisNP model calibration process (Hansson *et al.* 2008). Data needed for mountain monthly type-specific concentrations were replaced by arable land type-specific monthly concentrations. The type-specific concentrations of arable land were derived from long-term agricultural run-off monitoring data (N_{tot} 7.4 mg l^{-1} and P_{tot} 0.165 mg l^{-1}) provided by Latvia University of Agriculture. Afterwards mountain pollution loads were referred to arable land.

After the calibration for the period 2000–2010 (132 months), the model efficiency coefficient for nitrogen was $E = 0.498$, fairly good, and the correlation coefficient was $r = 0.71$, but for the phosphorus model $E = 0.28$ and $r = 0.60$ (Figs 6 and 7).

To estimate mean retention (Table 3) for each subcatchment model output results for gross and net contribution is taken into account:

$$\text{Retention } [\%] = 100\,(\text{Gross} - \text{Net})\,\text{Gross}^{-1}.$$

Internal gross contribution (before retention) and net contribution (after retention) is given for entire period of 11 years. Originally projected significant

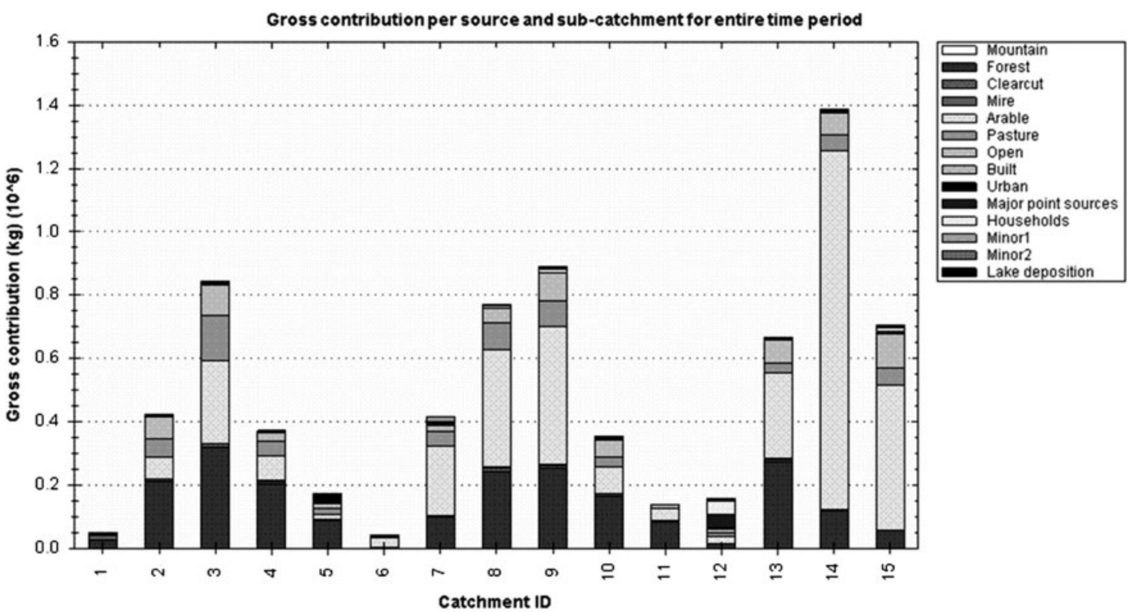

Fig. 8. N_{tot} loads and source apportionment in Bērze River subcatchments (2000–2010)

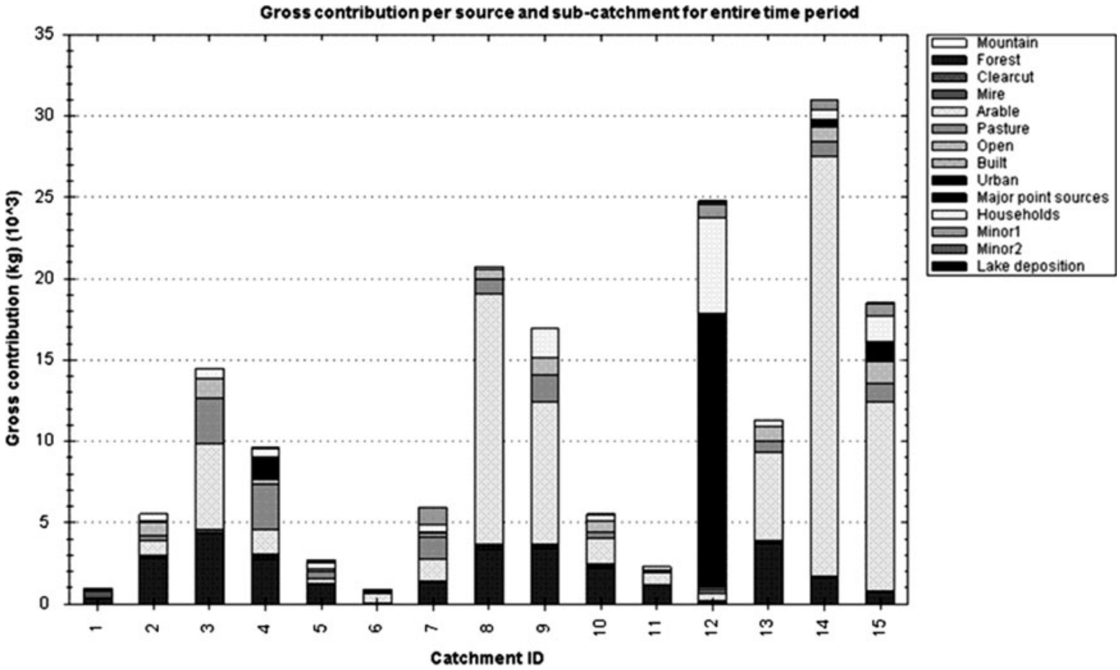

Fig. 9. P_{tot} loads and source apportionment in Bērze River subcatchments (2000–2010)

retention of total nitrogen and phosphorus in Annenieku HPP reservoir (ID 6) has not been confirmed even the model results show highest nitrogen and phosphorus retention rate in lake subcatchment (ID 5) 41.3% and 69.1%, respectively. This could be explained by fast water turnover in reservoir (Vassiljev, Stålnacke 2005).

Load compilation for both total nitrogen and total phosphorus is based on gross contribution (Table 3): Load [kg ha^{-1} year^{-1}] = Gross*Area^{-1}Years^{-1}.

Nowadays the nutrient loading from diffuse sources is the major source of anthropogenic nutrients in many areas since water protection measures have been applied to point sources (Povilaitis 2008). Agriculture is the main source of diffuse loads. Diffuse source impact of the each subcatchments is calculated as percentage distribution of leakage using the weighted average which is calculated by multiplying each subcatchment area with an average concentration (type-specific) and the annual runoff volume divided

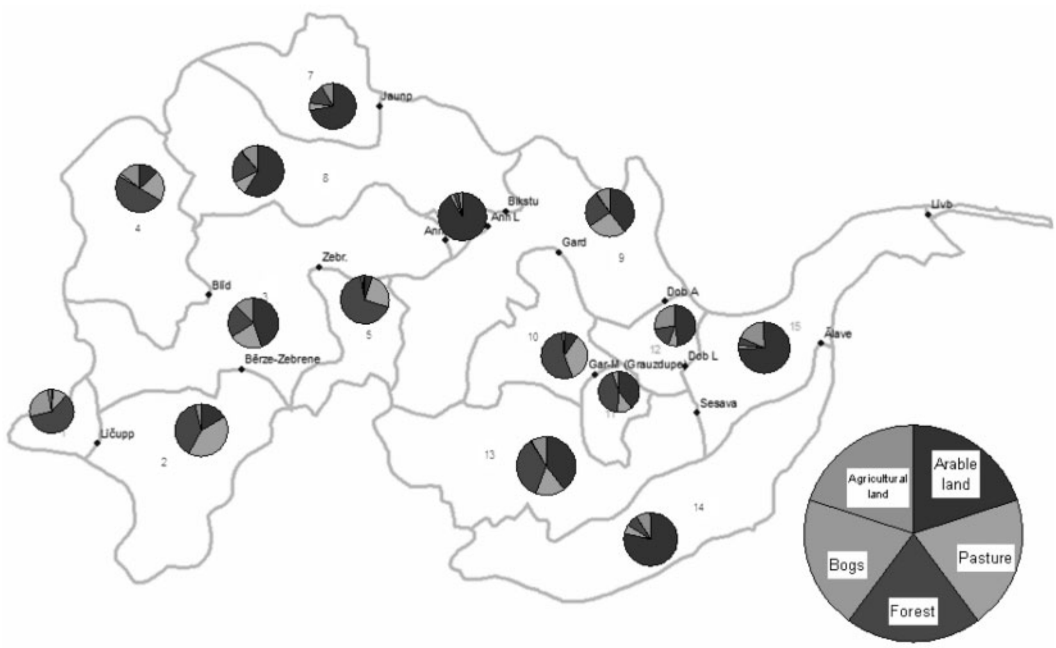

Fig. 10. N_{tot} diffuse source apportionment in Bērze River subcatchments (2000–2010)

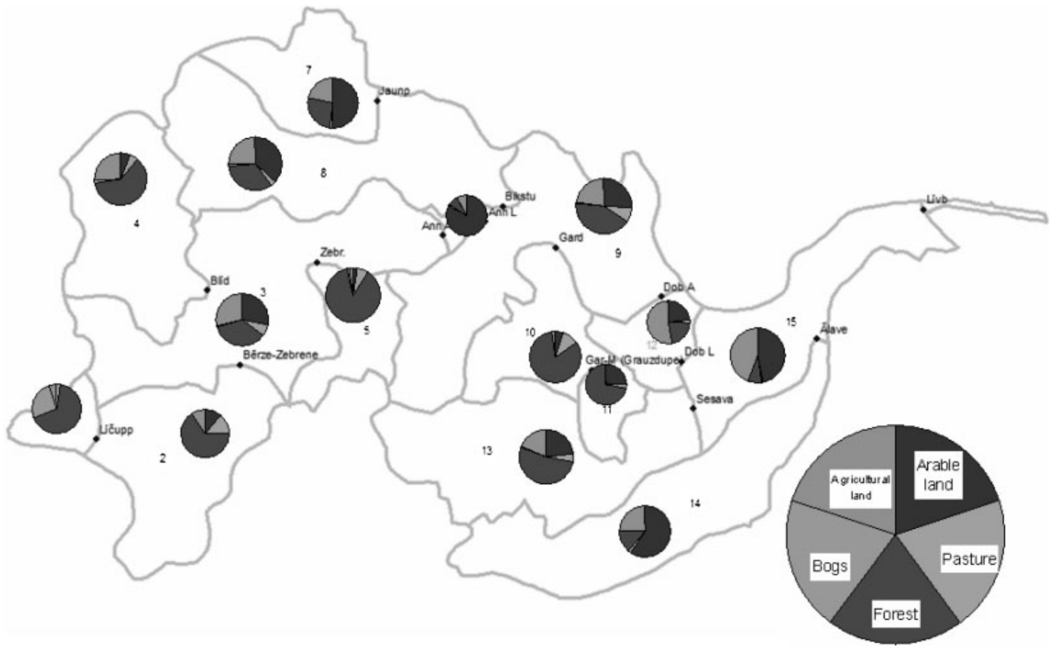

Fig. 11. P_{tot} diffuse source apportionment in Bērze River subcatchments (2000–2010)

by the total nitrogen or phosphorus loads (tons year^{-1} or kg year^{-1}).

Namely, nitrogen and phosphorus releases from each subcatchment (Monaghan *et al.* 2007) area divided by the total nutrient loads per year, resulting in the proportional distribution:

Impact $_i$, [%] = 100 (A_i R $Conc_{(i)}$) L_{tot}^{-1},

A_i – type-specific area for diffuse sources, ha;

R – annual run-off in Bērze River, mm;

$Conc_{(i)}$ – type-specific concentration, mg l^{-1};

L_{tot} – total annual load of nitrogen or phosphorus from the subcatchment, kg.

In order to implement river basin management plans both total loads (Figs 8 and 9) and diffuse source apportionment (Figs 10 and 11) estimations should be given to decision makers. For example, total loads per each subcatchment give an impression of priorities where the pollution potential is the highest (ID 14) and which subcatchments to treat first, while diffuse source apportionment pie-diagrams (Figs 10 and 11) show the background (forest, bogs) and anthropogenic (agricultural land, arable land and pasture) pollution apportionment (Pieterse *et al.* 2003).

Assuming that background pollution is rather nonsense to treat then the plan of action should be set only for agricultural, arable and pasture dominant subcatchments (Figs 10 and 11) with regard of appropriate pollution reduction measures. If more stringent measures are not taken to reduce emissions from agriculture, the improvement of a water quality may turn out to be too small to achieve good status in water bodies. After the proper model calibration it will be possible to assess future climate scenarios of water quality with a variety of contributing to pollution or cutting measures, as well as the impact of climate variability.

Conclusions

1. Accurate and precise model calibration requires hydro-chemical database that covers the period of observation with various hydro-meteorological conditions for more than 5 years.
2. The FyrisNP model calibration needs to be improved – model efficiency for nitrogen is $E = 0.498$, and the correlation coefficient is $r = 0.71$, but for the phosphorus model $E = 0.28$ and $r = 0.60$.
3. It was found that NO_3-N ratio against N_{tot} as well as PO_4-P ratio against P_{tot} is higher in agricultural lands compared to forests or bogs.
4. The model results show highest nitrogen and phosphorus annual retention coefficients in lake subcatchment (ID 5) – 41.3% and 69.1%, respectively, but the lowest in Dobele city (ID 12) subcatchment – 2.9% and 7.3%, respectively.
5. The output results of pollution source apportionment on the subcatchment basis could help river basin management decision makers to point out the catchments for agricultural mitigation measures.

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