Statistical modelling of riverine nutrient sources and retention in the Lake Peipsi drainage basin

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Abstract Implementation of the Water Framework Directive calls for methodologies and tools to quantify nutrient losses from diffuse sources at a river basin district scale. Here, we examine the possibility of using a statistical model for source apportionment and retention of nutrients in a large transboundary drainage basin (44,000 km²). The model approach uses non-linear regression for simultaneous estimation of e.g. source strength, i.e. export coefficients to surface waters, for the different specified land-use or soil categories and retention coefficients for pollutants in a drainage basin. The model was tested on data from 26 water quality stations with corresponding sub-basin data, i.e., land cover, point sources and atmospheric deposition, from the Estonian part of the Lake Peipsi drainage basin. The model showed that it was statistically possible to derive reliable export coefficients (i.e. unit-area loads) for nitrogen on agricultural land and forests. Moreover, it was shown with simple empirical functions that lake retention was approximately 30-35% for both nitrogen and phosphorus and that the riverine retention was low for both nitrogen and phosphorus (approx. 10%). Results show that the MESAW model is a simple and powerful tool for simultaneous estimation of sources and retention of nutrient loads in a river basin.

Keywords Export coefficients; Lake Peipsi; land use; nutrients; retention; source apportionment

Introduction Prerequisites for successful environmental management of river basins include the collection of basic environmental statistics and quantitative assessments of the riverine loads including estimation of the pollution sources and retention in the drainage basin. The nutrient level and fluxes at a specific location in a river network depends on the pollution sources in the upstream area, and the transfer, retention, and loss of nutrients in the soil, groundwater, and surface water network. This is a complex function of biological, physical, and chemical processes. Therefore, models are needed to analyse how these processes influence nutrient fluxes from pollution sources to river outlets over large spatial and temporal scales. Several models for so-called source apportionment and retention have already been developed worldwide. However, basins in Eastern Europe are often regarded as ‘data-poor’ or ‘information-poor’ and characterised by highly varying quantity and quality of input data. This is particularly problematic in international or transboundary waters, where the amount of data may differ between countries both in terms of quantity and quality. As most of the existing models require very detailed and spatially consistent input data, their applicability may be limited. Thus, simple models or tools are needed to address the limitations in these basins. The development of such models is still in its infancy. In this paper we elucidate the possibility to use a statistical model (i.e., MESAW) for source apportionment and retention of nutrients in a drainage basin characterised as both data-rich (on the Estonian side) and data-poor (on the Russian side), and the magnitude of the nutrient loads and sources has been uncertain for a long time.
Database and methods

The MESAW-model is a statistical model for source apportionment of the riverine transport of pollutants (Grimvall and Stålnacke, 1996). This model approach uses non-linear regression for simultaneous estimation of source strength (i.e. export coefficients to surface waters) for the different land use or soil categories and retention coefficients for pollutants in a river basin or lakes. The basic principles and major steps in the procedure are as follows:

1. estimation of riverine loads at each water quality monitoring site;
2. subdivision of the entire drainage basin into sub-basins, defined by the monitoring sites for water quality and their upstream-downstream relationships (describing the river system);
3. derivation of statistics on e.g. land use, soil type, lake area, point source emissions and other relevant data for each sub-basin;
4. using a general non-linear regression expression with loads at each sub-basin as the dependent/response variable and sub-basin characteristics as covariates/explanatory variables.

More precisely, load at the outlet of an arbitrary sub-basin can with MESAW be estimated from the following general expression (Liden et al., 1999).

\[ L_i = \sum_{j=1}^{n} (1 - R_{ji})L_j + (1 - R)S_i + (1 - R)P_i + (1 - R)D_i + \epsilon_i \]  

where:

- \( L_i \) is the load at outlet of sub-basin \( i \);
- \( L_j \) is the load at outlet of nearest upstream sub-basin \( j \);
- \( R_{ji} \) is retention on the way from outlet of sub-basin \( j \) till outlet of sub-basin \( i \);
- \( n \) is the number of sub-basins located nearest upstream;
- \( S_i \) is the total losses from soil to water in sub-basin \( i \);
- \( P_i \) is point source discharges to waters in sub-basin \( i \);
- \( D_i \) is atmospheric deposition on surface waters in sub-basin \( i \);
- \( R \) is retention in sub-basin \( i \);
- \( \epsilon_i \) is the statistical error term.

The load at each sub-basin can be decomposed into contributions from sources located in sub-basins further upstream (the first term in formula above) and contributions from sources located within the sub-basin under consideration (the \( S_i \), \( P_i \) and \( D_i \) terms). It should be particularly noted that the parameterisation of the model is flexible and can be study-area specific. The model is fitted by minimising the sum of squares for the difference in observed and estimated load. In this study, \( P_i \) and \( D_i \) was assumed to be known and \( S_i \) was assumed to be a simple function of land use according to

\[ S_i = (\beta_1 a_{1i} + \beta_2 a_{2i} + \beta_3 a_{3i}), \]

where \( a_{1i} \), \( a_{2i} \) and \( a_{3i} \) respectively denote the area of agricultural land (arable land and pastures, forests and other land (mainly bogs, and urban areas) in the sub-basins \( i \), and \( \beta_1 \), \( \beta_2 \) and \( \beta_3 \) are unknown export coefficients (i.e. emission coefficients, unit-area loads) for the three land use categories.

Nutrients are normally retained temporally or permanently in watercourses. Retention, in the model expressed as a summary expression for all hydrological and biogeochemical processes that may decrease or transport or losses of nutrients, can be parameterised by any empirical function. In this study, we divided the retention into retention in lakes...
and river retention (i.e. instream retention). Both types of retention can be expressed according to the following general formula:

\[
R = \frac{1}{1 + \text{par} \times \text{fact}}
\]

\(par\) unknown parameter estimated by the model,

\(fact\) empirical function based on the input data available (e.g. lake area)

Retention was parameterised by the simplest possible function (i.e. \(fact\)). More precisely, we assumed that retention in lakes was a direct function of the lake area, and riverine retention a function of the drainage area.

Retention from an arbitrary sub-basin \(m\) to the river mouth \(R_{\text{mouth}}\) can be derived from:

\[
R_{m, \text{mouth}} = 1 - \prod_{j=1}^{k} (1 - R_j)
\]

where

\(R_{m, \text{mouth}}\) retention from the outlet of the subwatershed \(m\) on the way to the mouth of the whole river;

\(k\) number of sub-basins downstream sub-basin \(m\);

\(R_j\) the values of retention within the different sub-basin downstream sub-basin \(m\)

The estimated source strength (e.g. export coefficients for agricultural land) and retention parameters were finally used to calculate the contribution from each source and sub-basin to the riverine load at the mouth(s). Further details regarding the general matrix expression for source strength and retention functions can be found in Grimvall and Stålmancke (1996).

Lake Peipsi is the fourth largest lake in Europe (Figure 1). The drainage basin is approximately 44,000 km\(^2\); 36% in Estonia, 57% in Russia and 7% in Latvia. Agricultural land and forests cover 42% and 40% of the total drainage basin, respectively. In this paper, we restrict the analyses to data from the Estonian part of the basin (15,700 km\(^2\); Table 1).

Time series of total-N and total-P concentrations and data on runoff were obtained from the Estonian Environmental Information Centre. The study period was fixed to 1993–2000 and data from a total of 22 gauging stations, 26 water quality monitoring sites and precipitation sites, were collected. The same data holder also provided us with subwatershed delineation maps, a database on the point source emissions, and data on atmospheric deposition. The latter data was set to 500 kg km\(^{-2}\) for N and 5 kg km\(^{-2}\) for P. The digital CORINE land cover map was used to derive land use statistics for each of the 26 sub-basins (Table 1), defined by the sites for water quality monitoring.

Water discharge at the ten water quality sites that lacked measurements were extrapolated from the most adjacent upstream sites with flow measurements. Since water discharge may vary with land use and precipitation, we have to take that into account in the extrapolation. More precisely, we firstly analysed the relationship between water discharge and land use by using the MESAW model, i.e., by replacement of load by water discharge in formula 1. The following formula was used to obtain corrected water flow.

\[
\text{Flow}_{\text{cor}} = \text{Flow} \times \frac{\sum_{i=1}^{3} \text{flow}_i \times \text{Area}_{i,1}}{\sum_{i=1}^{2} \text{flow}_i \times \text{Area}_{i,2}}
\]

where:
Flow – water flow received using ratio between area of subwatersheds without measurements of water flow and representative subwatershed,

$flow_i$ – water flow from $i$-th land cover area (mm), obtained by MESAW,

$Area_{i,1}$ – area occupied by $i$-th land cover type in the subwatershed without measurements,

$Area_{i,2}$ – area occupied by $i$-th land cover type in the subwatershed with measurements.

Annual load of tot-N and tot-P at each water quality site were finally calculated by multiplying daily water discharge with the observed or linearly interpolated concentrations. The time-averaged loads at each site are shown in Table 1.

**Results and discussion**

Results showed that water flow from forests at all sites and years were lower than water flow from agricultural land (ratio on average 0.67), due to higher evapotranspiration in forests due to higher leaf-area (mainly coniferous forest). However, the ratio between flow from agricultural land and flow from forest was found not to be constant over the annual cycle. More precisely, a more thorough analysis showed that this ratio was higher during the agricultural growing season (May – October; Figure 2) and the cold season (November-April) was characterised by almost the same water flow from agricultural land and forests.

The results from the model runs, which were conducted for each year separately, showed that the unit-area losses of nitrogen and phosphorus from agricultural land varied between 6.9–15 kg N ha$^{-1}$ and 0.17–0.63 kg P ha$^{-1}$. Interestingly, our estimates corroborate well with the results of monitored losses from a small agricultural catchment (i.e., Oostriku, 29.7 km$^2$). In addition, our results showed that the nitrogen losses from agricultural land were almost four times higher than the corresponding losses from forested land (Table 2). The annual estimated emission coefficients (i.e. unit-area loads) were then

![Figure 1 Lake Peipsi and its drainage basin with examples of water quality sites and major cities. Source: Royal Institute of Technology, Sweden (http://www.mantraeast.org/gis/)](http://www.mantraeast.org/gis/)
Table 1 Drainage area, time-averaged annual Tot-N and Tot-P loads, land cover distribution and urban point sources in sub-basins of the Estonian part of the Lake Peipsi drainage basin

<table>
<thead>
<tr>
<th>Sub-basin</th>
<th>Area (km²)</th>
<th>N-load (tonnes yr⁻¹)</th>
<th>P-load (tonnes yr⁻¹)</th>
<th>Agriculture land (%)</th>
<th>Forest (%)</th>
<th>Other land (%)</th>
<th>Lakes (%)</th>
<th>Point sources (tonnes N yr⁻¹)</th>
<th>Point sources (tonnes P yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Võhandu – Vagula</td>
<td>495</td>
<td>138</td>
<td>5.4</td>
<td>16.3</td>
<td>75.3</td>
<td>6.5</td>
<td>2.0</td>
<td>0.74</td>
<td>0.18</td>
</tr>
<tr>
<td>Võhandu – Himmiste</td>
<td>848</td>
<td>292</td>
<td>22.1</td>
<td>24.0</td>
<td>71.2</td>
<td>4.2</td>
<td>0.7</td>
<td>2.58</td>
<td>0.63</td>
</tr>
<tr>
<td>Võhandu Räpina</td>
<td>1,144</td>
<td>375</td>
<td>24.6</td>
<td>19.2</td>
<td>65.8</td>
<td>13.9</td>
<td>0.4</td>
<td>37.93</td>
<td>6.55</td>
</tr>
<tr>
<td>V-Emajõgi – Tõlliste</td>
<td>1,054</td>
<td>535</td>
<td>26.6</td>
<td>28.2</td>
<td>65.3</td>
<td>5.4</td>
<td>1.0</td>
<td>49.07</td>
<td>8.43</td>
</tr>
<tr>
<td>V-Emajõgi – Pikasilla sild</td>
<td>1,270</td>
<td>601</td>
<td>26.2</td>
<td>15.1</td>
<td>77.5</td>
<td>7.4</td>
<td>0.0</td>
<td>49.63</td>
<td>8.53</td>
</tr>
<tr>
<td>Õhne Tõrva</td>
<td>268</td>
<td>120</td>
<td>4.3</td>
<td>17.7</td>
<td>64.3</td>
<td>15.9</td>
<td>1.8</td>
<td>2.61</td>
<td>0.44</td>
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<tr>
<td>Õhne Suisepa</td>
<td>577</td>
<td>318</td>
<td>10.0</td>
<td>31.3</td>
<td>62.0</td>
<td>6.4</td>
<td>0.2</td>
<td>6.10</td>
<td>1.22</td>
</tr>
<tr>
<td>Tänassilma Õlu</td>
<td>454</td>
<td>281</td>
<td>12.8</td>
<td>26.9</td>
<td>62.3</td>
<td>10.5</td>
<td>0.2</td>
<td>17.21</td>
<td>2.87</td>
</tr>
<tr>
<td>Emajõgi Rannu-Jõesuu</td>
<td>3,374</td>
<td>827</td>
<td>35.6</td>
<td>24.5</td>
<td>46.1</td>
<td>5.2</td>
<td>23.8</td>
<td>83.6</td>
<td>14.38</td>
</tr>
<tr>
<td>Emajõgi Tartu</td>
<td>7,828</td>
<td>3,294</td>
<td>96.6</td>
<td>29.5</td>
<td>57.3</td>
<td>12.1</td>
<td>1.0</td>
<td>160.56</td>
<td>31.92</td>
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<tr>
<td>Emajõgi Kavastu</td>
<td>8,539</td>
<td>3,828</td>
<td>147.2</td>
<td>40.8</td>
<td>47.1</td>
<td>11.1</td>
<td>0.3</td>
<td>322.18</td>
<td>56.93</td>
</tr>
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<td>Pedja Jõgeva</td>
<td>665</td>
<td>437</td>
<td>6.4</td>
<td>27.8</td>
<td>64.2</td>
<td>7.9</td>
<td>0.0</td>
<td>1.90</td>
<td>0.82</td>
</tr>
<tr>
<td>Pedja Tõrve</td>
<td>776</td>
<td>537</td>
<td>10.7</td>
<td>35.7</td>
<td>49.7</td>
<td>13.8</td>
<td>0.8</td>
<td>24.47</td>
<td>4.47</td>
</tr>
<tr>
<td>Põltsamaa Rutikvere</td>
<td>861</td>
<td>694</td>
<td>7.8</td>
<td>33.4</td>
<td>54.4</td>
<td>11.7</td>
<td>0.5</td>
<td>4.91</td>
<td>1.85</td>
</tr>
<tr>
<td>Porrjõgi Reola</td>
<td>241</td>
<td>84</td>
<td>3.0</td>
<td>17.7</td>
<td>79.8</td>
<td>2.1</td>
<td>0.4</td>
<td>1.09</td>
<td>0.19</td>
</tr>
<tr>
<td>Ahja Kidiärve</td>
<td>336</td>
<td>122</td>
<td>5.2</td>
<td>23.5</td>
<td>73.0</td>
<td>3.4</td>
<td>0.2</td>
<td>2.26</td>
<td>0.57</td>
</tr>
<tr>
<td>Ahja Lääniste</td>
<td>930</td>
<td>345</td>
<td>21.5</td>
<td>25.5</td>
<td>66.1</td>
<td>8.2</td>
<td>0.1</td>
<td>16.54</td>
<td>5.76</td>
</tr>
<tr>
<td>Kääpa väljavool Kose paisjärvest</td>
<td>282</td>
<td>102</td>
<td>2.8</td>
<td>16.8</td>
<td>72.3</td>
<td>9.9</td>
<td>1.0</td>
<td>0.15</td>
<td>0.04</td>
</tr>
<tr>
<td>Avijõgi Mulgi</td>
<td>366</td>
<td>311</td>
<td>3.7</td>
<td>18.8</td>
<td>73.3</td>
<td>7.8</td>
<td>0.0</td>
<td>0.53</td>
<td>0.09</td>
</tr>
<tr>
<td>Ranna-pungerja Roostoja</td>
<td>313</td>
<td>219</td>
<td>3.3</td>
<td>9.6</td>
<td>65.3</td>
<td>25.1</td>
<td>0.0</td>
<td>42.61</td>
<td>0.46</td>
</tr>
<tr>
<td>Tagajõgi Tudulinna</td>
<td>252</td>
<td>162</td>
<td>3.1</td>
<td>2.3</td>
<td>77.9</td>
<td>19.7</td>
<td>0.1</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Alajõgi Alajõe</td>
<td>140</td>
<td>109</td>
<td>1.7</td>
<td>7.3</td>
<td>74.5</td>
<td>18.0</td>
<td>0.2</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
used to establish relationships between the emission coefficients and water discharge individual years for each land use category (Table 2).

As already mentioned in the previous section, retention in lakes and retention in the river systems were parameterised separately. The area of lake was used as covariate for retention in lake and area of subwatershed for retention in the river system. For nitrogen, the parameter for the lake retention was found to be highly statistically significant all years \((p < 0.01)\) while the corresponding analyses of retention in river systems were much more uncertain \((p > 0.05)\). For phosphorus, the estimated parameters were much more uncertain \((p < 0.05)\). This is perhaps not surprising since it is well known that nutrient retention capacity of a river basin is dependent on other factors: trophic status, depth of the waterbody, water residence time, nitrogen loading, loading of organic matter, denitrification activity (primarily dependent on sufficient amounts of reducable organic substrates, low oxygen concentrations and high temperature). Regardless of the simple parameterisation of retention and the uncertain parameter estimates (especially for phosphorus) our results clearly indicate that retention in lakes is substantial for both nitrogen and phosphorus (Table 3). Nitrogen retention in lakes in the North Atlantic Ocean region has in literature been reported to range from 20 to 80\% (Howarth \textit{et al.}, 1996). In the Nordic/Baltic region, lake retention is generally regarded as high. \textit{Jansson et al.} (1994) proposed that productive lakes might remove up to 50\% of total N-input. Studies carried out in Sweden show 50\% retention of total nitrogen in two eutrophic lakes with water residence time of 2.5 years (\textit{Ahlgren \textit{et al.}, 1994}). \textit{Svendsen and Kronvang} (1993)

**Table 2** Relationships between emission coefficients (kg ha\(^{-1}\)) of nitrogen and phosphorus and water discharge \((Q\text{ in mm yr}^{-1})\) from different land-use categories. Range of minimum and maximum flow was 119 and 300 mm, respectively

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural land</td>
<td>(\beta_1 = 0.0388Q + 3.76 (R^2 = 0.74))</td>
<td>(E = 0.0019Q - 0.06 (R^2 = 0.96))</td>
</tr>
<tr>
<td>Forest</td>
<td>(\beta_2 = 0.0095Q + 0.58 (R^2 = 0.57))</td>
<td>(E = 0.00012Q + 0.022 (R^2 = 0.49))</td>
</tr>
</tbody>
</table>

**Table 3** Estimated lake and river system retention of nitrogen and phosphorus

<table>
<thead>
<tr>
<th>Type of retention</th>
<th>Nitrogen retention (%)</th>
<th>Phosphorus retention (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lakes</td>
<td>33</td>
<td>35</td>
</tr>
<tr>
<td>River system</td>
<td>11</td>
<td>14</td>
</tr>
</tbody>
</table>

**Figure 2** Relationship between the ratio of water discharge from agricultural land and forests vs. the relative water discharge during May–October
estimated that the sedimentation and denitrification rates in Danish lakes vary between
33-48%. Information in the Baltic States is much scarcer. It is no doubt that lakes gener-
ally act as nutrient sinks, especially lakes in a steady state (equilibrium). However, at cer-
tain circumstances, lakes may act as a nutrient source rather than a sink. For example,
Svendsen et al. (1995) showed negative P-retention for a shallow lowland lake in
Denmark.

Regarding riverine (or instream) retention, the most important factors are assimilation
by algae and aquatic macrophytes and especially gaseous losses via denitrification. P is
removed by adsorption onto streambed sediments, sedimentation, and through uptake by
algae and aquatic macrophytes. In literature, special attention has been given to erosion
processes (soil and bank erosion) and P adsorption and desorption processes in streams.
The adsorption onto bed sediments is regarded to be the major mechanism for P retention.
In the Ruhr River, Imhoff (1989) estimated an instream P-retention of 50%. However,
observations that main river channels can act as sources rather than sinks have also been
observed. Svendsen et al. (1995) showed in a Danish lowland stream a negative P-retention
on an annual basis due to resuspension of retained material during high flows and
stream bank erosion. On the other hand it was in the same study shown that the retention
of DRP (dissolved reactive P) constituted up to 60% of the DRP input to the stream chan-
nel, most likely due to P uptake in benthic and pelagic algae rather than P uptake by
aquatic macrophytes. The impact of instream physical and biological processes on the
regulation of P fluxes through river systems is still poorly understood. Therefore, it is not
surprising that we in this study with simple empirical functions were less successful.

For nitrogen, riverine retention estimates are much more scattered. A recent literature
review by Haag and Kaapenjohann (2001) stated that the nitrate-N retention in rivers
most likely is in the range of 1–5%, although values of 20% and 30% also have been
reported by Hill (1997) and Billen et al. (1991), respectively. In the Nordic/Baltic region,
instream retention is regarded as low. Arheimer (1998) indicated in calculations for entire
southern Sweden an instream retention of 2% or maximum 7% (B. Arheimer, personal
communication). In the Kasari river in Estonia, in-stream retention was found to account
for less than 10% (Lidén et al., 1998). Thus, the relatively low derived retention in rivers
found in this study (Table 3) may be regarded as rather non-controversial. Instream reten-
tion can also occur in open channels in the agricultural landscape. In fact, it has in catch-
ments in the Baltic States been shown that up to 60% of the load at tile drain outlets is
lost on its way to the mouth of the open channel (first-order stream). In this study, we
have most likely not been able to capture this possible phenomenon but it will be further
examined later.

Based on the model results, we for 1993 found that more than 60% of the total nitro-
gen originated from agricultural land (Table 4). Forest, despite the large areal coverage
(Table 1), contributed with less than 30% of the nitrogen load. The corresponding results
for phosphorus showed that approximately 40% of the load originated from agricultural
land while point sources accounted for approximately 42%.

The main uncertainty in model runs was found to be for phosphorus. This was rather
expected since phosphorus loads also depend on other factors than land use (e.g., soil
type). Despite these discerned uncertainties, it seems that the MESAW model is a reliable

<table>
<thead>
<tr>
<th>Source</th>
<th>Agricultural land</th>
<th>Forest</th>
<th>Other</th>
<th>Point sources</th>
<th>Deposition on the lakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (%)</td>
<td>61</td>
<td>27</td>
<td>2</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>40</td>
<td>16</td>
<td>1</td>
<td>42</td>
<td>1</td>
</tr>
</tbody>
</table>
tool for simultaneous estimation of sources and retention in a river basin. It was also evident that MESAW can be used to investigate the water flow from different types of land cover. In addition, MESAW can be used to identify measurements that are outside the general patterns and relationships (i.e., outliers). The main advantages with the model are: (i) the simple structure of the model (ii) the simple input data (iii) all unknown parameters are derived from empirical data, and (iv) that information from all water quality monitoring sites is used in an optimal way. The main advantage of the MESAW is that it gives results on the base of all available measured data which is better than to apply emission coefficients received from literature; normally even extrapolated from other regions or up-scaled from small watersheds. MESAW has many common features with the more famous SPARROW model developed in USA (Smith et al., 1997; Alexander et al., 2000). It should be pointed out that the examples given in this article are performed deliberately with very simple input data and parameterisation. This implies that we have a good possibility to apply the model for the entire Lake Peipsi region, i.e. also on the Russian side where data is far more limited.

Conclusions
Results show that less than 10% of the nitrogen load from Estonian rivers to Lake Peipsi originates from wastewater (point pollution sources); approximately 60% of the load comes from agriculture and 30% originates from forests and other diffuse sources. Of the phosphorus load, over 40% comes from point pollution sources and almost 40% from agriculture via the rivers in the catchment area. Estimation of retention was found to be large in lakes: 30-35% in lake Võrtsjärv for nitrogen and phosphorus. Riverine retention of phosphorus was found to be difficult to assess but estimated to be less than 15% while riverine retention of nitrogen was found to be somewhat smaller; i.e., approximately 10%.

Results show that the MESAW model is a simple tool for simultaneous estimation of sources and retention in a river basin due to (i) the simple structure of the model (ii) the simple input data (iii) that all unknown parameters are derived from empirical data, and (iv) that information from all water quality monitoring sites is used in an optimal way. Results also showed that it could be powerful to analyse the relationships between water discharge and land use. For example, in this study we showed that water discharge from agricultural land generally was higher than from forests, especially during the growing season.

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References


