Scale issues for assessment of nutrient leaching from agricultural land in Latvia

Ainis Lagzdins, Viesturs Jansons, Ritvars Sudars and Kaspars Abramenko

ABSTRACT

This paper deals with water quality assessment and recommendations for a classification system based on nitrogen (N) and phosphorus (P) concentrations. In order to evaluate the influence of agricultural intensity, climate and hydrology on water quality, the long-term data (from 1995 to 2009) collected in three Latvian diffuse pollution monitoring sites (Berze, Mellupite and Vienziemite) were analysed. Measurements were carried out within areas where agriculture was the main source of diffuse nutrient loading at four spatial scales, i.e. experimental plot, drainage field, small catchment and river. The available long-term data series shows large variations in nutrient concentrations, depending on the intensity of agricultural production system and the scale of measurements. The concentrations of total N are higher at the plot scale, decreasing when the spatial scale of measurements increase. The proposed simplified classification system (five classes) was based upon the assumption that good chemical status for rivers in agricultural areas represent concentrations of total N < 1.5 mg L\(^{-1}\) and total P < 0.075 mg L\(^{-1}\), while in small catchments total N < 2.5 mg L\(^{-1}\) and total P < 0.050 mg L\(^{-1}\) and in subsurface drainage water total N < 5.5 mg L\(^{-1}\) and total P < 0.020 mg L\(^{-1}\).

Key words | agricultural runoff, monitoring scales, nitrogen, phosphorus, probability distribution

INTRODUCTION

Excessive amounts of nutrients can lead to eutrophication, which harms the water environment affecting water ecological status and use for human needs. In several investigations (USGS 1999; Randall & Mulla 2001; Vuorenmaa et al. 2002) it was reported that water balance of the humid soils causes nitrogen and phosphorus leaching from natural and agricultural sources. The nutrient concentrations in streams strongly correlate with the percentage of arable land in agriculture – the main source of diffuse pollution. This was noted in several studies concerning scale of monitoring by Jansons et al. (2005) in Latvia, Sileika et al. (2005) in Lithuania, and Kyllmar et al. (2006) and Ulén & Fölster (2007) in Sweden. HELCOM (2009) reported that diffuse inputs constitute 71% of the total nitrogen and 44% of total phosphorus load into surface waters within the Baltic Sea catchment area. Agriculture alone contributed about 80% of diffuse load of nitrogen. However, the role of agriculture may be somewhat more significant as a result of increased implementation of nutrient removal measures in the municipal sector.

The accelerated nutrient enrichment or eutrophication of water bodies from anthropogenic sources have become a significant water quality problem in most EU countries. In 1991, the Nitrate Directive (ND) was imposed with the aim of reducing concentrations of nitrogen in water ecosystems (EC 1991). The later European Water Framework Directive (WFD), imposed in 2000, introduced new targets for water quality at levels closer to those which may be seen under natural conditions, without considerable human impact, i.e. good water quality should be reached by 2015 (EC 2000). In view of the requirements of the ND and WFD and the future implementation of the directives, a list of possible quantitative water quality parameters will also be valuable for decision making, for water management.

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planning and assessment of the efficiency of planned measures, e.g. Action Programs (ND) and Programs of Measures (WFD).

Water quality evaluation requires consideration of the water body types at different spatial and geographical scales. In humid soils this can be analysed at several different scales: (1) drainage plot scale, (2) drainage field scale, (3) small agricultural catchment scale and (4) river scale. Each scale has the following specific meaning in water quality evaluation:

1. Drainage plot scale: represents the relationships between soil, plant, nutrients and water. The nutrients leaching from farm land with different application rates and timing of mineral and organic fertilizers for various crops and soil management are studied in this scale.

2. Drainage field scale: shows integrated effects of crop rotation and application of fertilizers on the water quality. At this scale it may be possible to aggregate the results of plot studies, and to relate them to patterns of nutrient transport at the drainage field outlet.

3. Small agricultural catchment scale: represents the influence of variations in farming practices, erosion processes, soil types and topography within the catchment.

4. River scale: the impact of the climate conditions, land use distribution, different pollution sources, including point sources, and retention processes from headwaters to the downstream part of the river on water quality can be analysed.

A long-term sampling programme is necessary due to the large variability that can occur annually in the intensity of nutrient/algal problems, due to timing of weather (primarily scouring storm events or persistent low flow events with long residence time) and seasonality of nutrient runoff. Ideally, water quality monitoring programmes produce long-term datasets compiled over multiple years, to capture the natural, seasonal and year-to-year variations in nutrient concentrations.

In Latvia, the agricultural runoff monitoring programme to determine the impact of agriculture on water quality was started in 1995. Cooperation with the Nordic countries promoted the establishment of the network of monitoring stations in Berze, Mellupite and Vienziemite sites with hydraulic measurement structures and recording equipment. The Department of Environmental Engineering and Water Management of Latvia University of Agriculture is responsible for this monitoring programme (Jansons 2009).

The main objectives of the study presented in this paper were: (i) to analyse water quality data (total N and total P) obtained in different spatial scales and under different intensity of agricultural practices, (ii) to evaluate losses of total N and total P in catchment and drainage field scales, and (iii) to create scientifically based criteria for water quality classification in agricultural areas.

**MATERIALS AND METHODS**

**General description of the monitoring sites**

The selected research sites of Berze, Mellupite and Vienziemite are situated in the different parts of Latvia (Figure 1) and represent regions with various climatic conditions, soil texture, slopes and farming intensity. According to the WFD, four river basin districts have been established in Latvia. Study sites represent Lielupe, Venta and Gauja river basin districts. Under the ND, EU countries had to identify nitrate vulnerable zones (NVZ). Only Berze monitoring site is located within NVZ where the action programmes with measures concerning good agricultural practices should be implemented.

Long-term (1995–2009) variation of runoff conditions and total N and total P concentrations were analysed in four spatial scales. The small catchments studied vary in size from 368 to 960 ha and all of them are dominated by agricultural land that generally has tile-drainage (depth 1.1–1.3 m, and spacing between drains of 10–32 m). As stated by Jansons et al. (2003), the size of small catchments for the assessment of non-point source agricultural runoff of N and P to surface water is usually less than 10 km². The percentage of arable land in agriculture within catchments ranges substantially, from 5 to 10% in Vienziemite to 80 to 90% in Berze, while in Mellupite arable land represents 60 to 70%. The land in the drainage fields in Berze and Mellupite was used for arable crops. Drainage fields are situated within or nearby the catchments. The area of fields varies from 12 to 77 ha. Tile drainage has open
inlets for surface water in places where surface runoff is likely to accumulate. Open inlets are positioned preferably at the upstream end of the drain pipe in order to reduce the chance of the pipe being blocked by sedimentation (Ritzema 1994). Surface water inlets can be the pathway for the direct inflow of eroded soil particles during the surface runoff events. In studied sites the impacts from point sources, such as scattered households or animal farms, can be considered as negligible. Description of monitoring conditions and scales is presented in Table 1.

Berze monitoring site is situated in the central part of Latvia. The soil texture within the catchment is silt clay loam according to FAO (2006) classification. Due to natural soil fertility, this region can be characterised with relatively intensive cropping system compared with the present farming conditions in Latvia. Nitrogen fertilizer and manure application vary among catchment fields from 51 to 224 kg ha\(^{-1}\) year\(^{-1}\) while the phosphorus application ranges from 24 to 66 kg ha\(^{-1}\) year\(^{-1}\). The landscape in this area is flat, therefore the risk of the surface runoff is rather low. During the study period the three main crop types were sugar beet, oilseed rape and winter wheat. The crop proportion within the catchment changes over the years and is influenced by market demand. Recently, winter oilseed rape has become essential for biofuel production. In addition to drainage field and small catchment scale water

![Figure 1](https://iwaponline.com/hr/article-pdf/43/4/383/371109/383.pdf)

**Figure 1** | River basin districts within Latvia and location of the study sites.

<table>
<thead>
<tr>
<th>Monitoring site</th>
<th>Monitoring scale</th>
<th>Area (ha)</th>
<th>Agricultural land (%)</th>
<th>Flow measurement structure</th>
<th>Water sampling procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berze</td>
<td>Alave River</td>
<td>9368</td>
<td>74</td>
<td>No measurements</td>
<td>Manual</td>
</tr>
<tr>
<td></td>
<td>Small catchment</td>
<td>368</td>
<td>98</td>
<td>V-shape Crump weir</td>
<td>Flow proportional</td>
</tr>
<tr>
<td></td>
<td>Drainage field</td>
<td>77</td>
<td>100</td>
<td>Triangular weir</td>
<td>Flow proportional</td>
</tr>
<tr>
<td>Mellupite</td>
<td>Small catchment</td>
<td>960</td>
<td>69</td>
<td>Crump weir</td>
<td>Flow proportional</td>
</tr>
<tr>
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<td>12</td>
<td>100</td>
<td>Triangular weir</td>
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</tr>
<tr>
<td></td>
<td>Plot</td>
<td>0.36</td>
<td>100</td>
<td>Tipping buckets</td>
<td>Flow proportional</td>
</tr>
<tr>
<td>Vienziemite</td>
<td>Small catchment</td>
<td>592</td>
<td>78</td>
<td>Combined profile weir</td>
<td>Manual</td>
</tr>
<tr>
<td></td>
<td>Drainage field</td>
<td>67</td>
<td>100</td>
<td>Triangular weir</td>
<td>Manual</td>
</tr>
</tbody>
</table>
quality, monitoring of the Alave River began in 2005. For Latvia, the Alave River is a small-sized river (catchment area <100 km²) with a high percentage of agricultural land in the catchment. The Alave River and Berze site are located within the same region, thus evaluation of water quality can be carried out in three spatial scales.

The Mellupite catchment represents the western part of the country. The farming in this catchment is moderately intensive and typical for the present situation in agriculture in Latvia. The average application of nitrogen within this catchment ranges from 38 to 118 kg ha⁻¹ year⁻¹, while the phosphorus application rate varied from 10 to 52 kg ha⁻¹ year⁻¹. The main soil texture in the catchment is loam. The main crops in the catchment are cereals, i.e. winter wheat and spring barley. Experimental drainage plots were constructed in the Mellupite site in order to estimate the impact of different fertilization treatments on the water quality. Five treatments in three replicates are applied, i.e. normal mineral fertilizer rate, double mineral fertilizing rate, unfertilized, manure and slurry applications. Normal mineral fertilizer application plots are considered to have similar fertilizing rates as in the drainage and small catchment and therefore have been chosen for our evaluation of water quality in different spatial scales.

The Vienziemite monitoring stations are located in the north-eastern part of Latvia and it is a typical example of low input agricultural land use which can be used as a reference site for water quality assessment. A large proportion of the agricultural land is pasture, used for extensive cattle farming. Almost no fertilizers (average 4–5 kg N ha⁻¹ year⁻¹) are applied in this study site. Soil texture of this area is sandy loam which is a less favourable soil for agriculture. The landscape in the Vienziemite catchment is rather hilly for Baltic conditions.

**Measurement program**

The flow measurements in monitoring sites were based on fixed measurement structures and automatic data and sampling equipment for continuous water level registration and water sampling (Table 1). The water level was recorded hourly, while composite water samples were collected monthly based on a flow proportional sampling procedure, apart from the Vienziemite site where water samples were collected manually. Logger-triggered sampling frequency was usually 5–10 subsamples per day. The number of analysed water samples varied among monitoring sites and scales because sometimes monitored streams dry out during the summer. The total N and total P load (kg ha⁻¹) was calculated by multiplying the analysed concentrations of the composite water samples with the total volume of water that had discharged during the corresponding water sampling period. The linearly interpolated daily values were accumulated to calculate annual nutrient load values. Analysis of water samples for the detection of content of total N (Latvian Standards 1999) and total P (Latvian Standards 2005) in the water was carried out in laboratories according to Latvian Standard methods. Data of agricultural activities, such as crop rotations, timing and amount of mineral and organic fertilizers application and harvested yields, were collected from interviews with the farmers.

Long-term records at the nearest meteorological stations indicate the differences in climatic conditions. The observations were carried out by the Latvian Environment, Geology and Meteorology Centre.

**Statistical analysis**

As stated by Warner (2000), box and whisker plots can be used for graphical presentations of the total N and total P concentrations. The box and whisker plots show the minimum value, 25th percentile, median value, 75th percentile and maximum value of data set. Side by side, these types of plots are convenient for determining differences in medians and similarity in spreads. The box and whisker plots could also be used to calculate and show outliers and extremes of data set. It has been described by Berzina et al. (2008) that interquartile range (IQR) can be used for the identification of outliers and extremes. IQR is the difference between the first (25th percentile) and third quartiles (75th percentile). Any observations which are more than 1.5 × IQR and more than 3 × IQR above the third quartile or below the first quartile can be assumed as outliers or extremes, respectively. It is well known that observations with values considerably different from the others in the data set (e.g. Helsel & Hirsch 2002) are often cause for concern. In the present context, outliers can have three causes: (i) a measurement or recording error; (ii) an observation...
from a population not similar to that of most of the data, e.g., a flood caused by a dam break rather than by precipitation; or (iii) a rare event from a single population that is greatly skewed. The box and whisker plots calculations and visualisations were performed by the software package SPSS (SPSS 2006).

The probability distribution functions could be used to represent a random variable and to determine the probability of occurrence. A number of probability functions, such as cumulative, normal, empirical and gamma, have been used in hydrological, climate and water quality studies such as cumulative, normal, empirical and gamma, have been used in hydrological, climate and water quality studies by Tung & Hathorn (1988) and von Storch & Zwiers (1999). In this study gamma distribution curves are used to illustrate nutrient concentration probability.

The Mann–Kendall test is the commonly used non-parametric method of detecting statistical trends in time series. In this study, the Mann–Kendall trend test with statistical significance $p < 0.05$ was used to analyse long-term changes in nutrient concentrations. Helsel & Hirsch (2002) stated that the Mann–Kendall test can be used as a test to determine whether $Y$ values (concentrations) have no trend or trend to increase/decrease with $X$ variable (time). The Mann–Kendall test involves computing a statistic ($S$), which is the difference between the number of pluses, the number of times the $Y$s increase as the $X$s increase, minus the number of minuses, the number of times the $Y$s decrease as the $X$s increase. If $S$ is a large positive value, then there is evidence of an increasing trend in the data. If $S$ is a large negative value, then there is evidence of a decreasing trend in the data. If the value of Mann–Kendall $S$ is close to 0, it can be assumed that no temporal trend in concentrations is revealed. Mann–Kendall trend analysis was carried out using the software Time Trends (Time Trends 2010).

**RESULTS AND DISCUSSION**

**Climatic conditions and discharge**

Jansons et al. (2005) noted that Latvia is situated in a humid and moderately mild climatic region where rainfall exceeds evaporation, resulting in percolation losses from the soil. The highest mean annual air temperature was registered in Berze (7.5°C), followed by Mellupite (6.4°C) and Vienziemite (5.6°C). The snow cover in Latvia has an average duration of 80–90 days. The heavy snow cover and low temperatures in the north-eastern part of Latvia (Vienziemite) has an impact on water discharge in springtime. In this area snow and ice starts to melt later over a longer time period compared with other monitoring sites that are located in the central (Berze) and western parts (Mellupite) of country.

There was also a gradient in precipitation among the study areas. The mean daily precipitation in Berze was 1.58 mm, while in Mellupite it was 1.80 mm and in Vienziemite it was 1.96 mm. The daily mean precipitation values designate the same tendency as annual precipitation patterns. On the annual scale mean precipitation rate range from 578 mm in Berze and 656 mm in Mellupite to 717 mm in Vienziemite.

Site specific discharge is influenced by the temporal distribution of precipitation within a particular time period. It has been studied and approved by Jaynes et al. (2001), Vanni et al. (2001), Randall & Mulla (2001) and Oquist et al. (2007). Annual discharge varied greatly among research sites and study years, following the trends in precipitation. The time series of annual precipitation and water discharge data for monitored sites during the period 1995–2009 are illustrated in Figures 2, 3 and 4. Mean annual discharge in both small catchment and drainage field scales was highest in Vienziemite, 278 mm and 261 mm, respectively, while the lowest was in Berze, 153 mm in the small catchment and 155 mm in the drainage field. A typical feature that can be discerned from precipitation and discharge patterns is that in the Mellupite site the relationship between water discharges in both monitoring scales was very similar. In contrast, the discharges in Berze and Vienziemite vary considerably among study scales.

There is clear evidence that water discharge differences between monitored sites can be explained by precipitation rates in the particular study site, for example high rainfall in Vienziemite leads to high water discharge. In addition, soil texture properties within specific regions have an important role in the amount of drainage runoff from the soil profile. Sandy soils have less water field capacity than clay or silt loam soils, therefore leaching is induced more quickly in lighter soils. Poorly drained silt clay loam soil in the Berze catchment has higher water storage capacity, thus discharge responds slowly, whereas
well–drained sandy loam soil in Vienziemite promotes faster water percolation through soil profile which results in higher discharge volumes.

As expected in this climate, snowmelt in winter, spring floods and the rainy season in autumn were periods of highest discharge, and discharge was lowest in summer. The cumulative distribution of discharge (Figure 5) shows the time periods of intensive water flow, which also affects the nutrient losses. As described by von Storch & Zwiers (1999), in spring and autumn the wet soil has a lower capacity to store water so almost all rainfall is directly transferred to discharge. In summer the occurrence of precipitation is much more variable and the dry soil is able to store a significant amount of water. Thus, minor rain events have little impact on the discharge.

**Nutrient concentrations**

In several investigations (e.g. Armstrong & Burt 1995; McDowell et al. 1997; Sharpley & Rekolainen 1997;
Van Herpe & Troch 2000; Donohue et al. 2001; Iital 2005; Bakhsh et al. 2007) it has been found that water discharge is the main transport pathway of nutrient contents from the soil profile into streams, therefore, hydrological patterns of monitoring sites must be taken into account when analysing nutrient concentrations. Both total N and total P concentrations data showed high variability over time, study sites and monitoring scales that were caused by the site specific land management activities and farming practices, including different farming intensity and application rate of mineral and organic fertilizers. Nutrient concentrations in runoff for the three monitoring sites are provided in Table 2. The results present minimum, maximum and mean values and coefficients of variation for all water samples during the monitoring period (1995–2009). The highest mean concentrations of total N were observed in plots and drainage fields compared with small catchments and rivers in the Berze and Mellupite sites, while in the Vienziemite site variation in N concentrations between monitoring scales was insignificant. The maximum concentration of total N (102.7 mg L$^{-1}$) was observed in the Berze drainage field in the autumn of 2006 when drainage discharge began after a very dry period in summer.

Due to the high temporal and spatial variation of total P concentrations it was difficult to draw conclusions regarding the variability of total P values in different monitoring scales. As described by Heathwaite (1997) and Sharpley & Rekolainen (1997), P may be exported via surface and subsurface hydrological pathways. Both particulate and dissolved P fractions are transported in surface runoff. Particulate P includes P adsorbed onto organic-rich clay particles and silt-sized soil fractions eroded during flow events and constitute the major proportion of P transported from cultivated land via surface runoff. Most of the subsurface transport of P is assumed to be in the soluble fraction where concentrations of soluble P percolating through soil are low, due to sorption of P by P-deficient sub-soils, exceptions occur in soils where adsorption affinity and capacity for P are low. For example, acid organic, sandy and peaty soils may have high leaching potential. In the autumn of 1998 in the drainage field scale in the Mellupite site (1.106 mg L$^{-1}$) and in the autumn of 1995 in the Berze small catchment (2.126 mg L$^{-1}$), water quality measurements showed a large increase in concentrations of P when soil erosion, due to the high surface runoff, was observed. In the Mellupite case, high concentrations of total P was a result of surface runoff in flow in the tile drainage system via open inlets.

The monthly concentrations of total N, presented as box and whisker plots (Figure 6), are used to describe seasonal variations in N leaching among study sites and scales. The variability in concentrations of total N in the Berze small
catchment is strongly related with the seasonal fluctuations of water discharge, while in the drainage field scale the concentrations are relatively stable over the seasons and do not follow water discharge patterns. The highest measured nitrogen concentrations of the Berze drainage field (102.7 and 45.1 mg L\(^{-1}\)) are not shown in Figure 6. High concentrations of total N in the autumn in the Mellupite drainage field outlet in the autumn season can be explained with the combination of fast response of tile drains to hydrological processes and post-harvest tillage that increase the erosion of the soil. In the Vienziemite site in both monitoring scales, the snow melt period could affect the increase of total N concentrations. In most cases data of monthly concentrations of the total N show seasonal fluctuations, with the lowest levels in the dry period of summer, and the highest from late autumn to spring. This agrees with earlier findings in large river scale studies in Latvia reported by Stålnacke et al. (2003). Thus, this study proved that within the small catchment and drainage field scales N leaching from agricultural land follows the seasonal patterns of water discharge and leaching mainly appears during the high discharge periods (autumn and spring seasons).
The trend analysis of nutrient concentrations was performed to characterise changes in concentrations over the study period. The results of the analysis of long-term trends of the N and P concentrations were interpreted using the Mann–Kendall test statistic. This statistical parameter is used to prove increases, decreases, or no temporal trend in the concentrations over the period of measurements. The trends in total N and total P concentrations determined in this study are presented in Figures 7–10, where time series of date are shown on the X-axis and the nutrient concentrations on the Y-axis.

In the catchment scale, statistically significant \((p < 0.05)\) upward trends in total N concentrations were revealed in the Berze and Mellupite sites, Mann–Kendall \(S\) value 2511 and 2486, respectively. Within these sites agricultural activities are intensive with rather high mineral and organic fertilizers applications, in Berze up to 224 kg of N ha\(^{-1}\) year\(^{-1}\) and in Mellupite up to 118 kg of N ha\(^{-1}\) year\(^{-1}\), whereas in Vienzimite the total N concentrations had increased statistically insignificantly \((p = 0.40)\), Mann–Kendall \(S\) value 730 (Figure 7). In the drainage field scale the situation was similar with a pronounced statistically significant \((p < 0.05)\) upward trend in total N concentrations in Berze (Mann–Kendall \(S = 4452\)) and Mellupite (Mann–Kendall \(S = 2493\)), while in Vienzimite a statistically insignificant \((p = 0.08)\) downward trend was fixed, Mann–Kendall \(S = -1439\) (Figure 8). A substantial increase of total N leakage in the Berze drainage field was related to changes of dominant crop type in the catchment area, from sugar beets to cereals, and with excessive application of mineral and organic fertilizers mentioned by farmers during annual interviews.

In the small catchment scale, total P concentrations had a statistically insignificant \((p > 0.05)\) upward trend during the study period in Mellupite (Mann–Kendall \(S = 104\)) and Vienzimite (Mann–Kendall \(S = 512\)), in Berze a statistically significant \((p < 0.05)\) downward trend was detected, Mann–Kendall \(S = -1661\) (Figure 9). It is evident from the interviews in the Berze catchment that farmers recently had changed the type of applied mineral fertilizers from rather expensive but high quality complex fertilizers to straight nitrogen fertilizers application which may have led to soil depletion, it resulted in increasing trend in total N and decreasing in total P. Total P concentrations at the drainage field scale were relatively low and with statistically insignificant \((p > 0.05)\) trends in Berze (Mann–Kendall \(S = 365\)) and Mellupite (Mann–Kendall \(S = -36\)), while in Vienzimite an upward trend in total P concentrations (Mann–Kendall \(S = 1493\)) was close to the level of statistical significance \((p = 0.07)\) (Figure 10). The specific character of total P transport, i.e. the main source of phosphorus losses was occasional erosion events induced by surface runoff, has to be taken into consideration when the trend analysis of total P concentrations is performed. Therefore, in most cases a minor temporal trend in total P concentrations can be observed.

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**Table 2**: Nutrient concentrations in monitoring sites, 1995-2009

<table>
<thead>
<tr>
<th>Monitoring site</th>
<th>Number of samples</th>
<th>Total N (mg l(^{-1}))</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>CV (%)</th>
<th>Total P (mg l(^{-1}))</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berze</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Alave River</td>
<td>57</td>
<td>0.80</td>
<td>19.90</td>
<td>5.28</td>
<td>82</td>
<td></td>
<td>0.032</td>
<td>0.243</td>
<td>0.097</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Small catchment</td>
<td>167</td>
<td>0.90</td>
<td>29.50</td>
<td>8.63</td>
<td>62</td>
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<td>0.018</td>
<td>2.126</td>
<td>0.165</td>
<td>121</td>
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</tr>
<tr>
<td>Drainage field</td>
<td>154</td>
<td>1.90</td>
<td>102.70</td>
<td>12.09</td>
<td>79</td>
<td></td>
<td>0.010</td>
<td>0.473</td>
<td>0.060</td>
<td>117</td>
<td></td>
</tr>
<tr>
<td>Mellupite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small catchment</td>
<td>172</td>
<td>0.53</td>
<td>16.30</td>
<td>3.68</td>
<td>67</td>
<td></td>
<td>0.004</td>
<td>0.709</td>
<td>0.082</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>Drainage field</td>
<td>142</td>
<td>1.60</td>
<td>16.80</td>
<td>7.25</td>
<td>37</td>
<td></td>
<td>0.003</td>
<td>1.106</td>
<td>0.072</td>
<td>144</td>
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<tr>
<td>Plot</td>
<td>64</td>
<td>2.80</td>
<td>31.67</td>
<td>10.10</td>
<td>53</td>
<td></td>
<td>0.004</td>
<td>0.686</td>
<td>0.097</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>Vienzimite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Small catchment</td>
<td>185</td>
<td>0.43</td>
<td>7.50</td>
<td>1.71</td>
<td>59</td>
<td></td>
<td>0.009</td>
<td>0.712</td>
<td>0.041</td>
<td>139</td>
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<tr>
<td>Drainage field</td>
<td>179</td>
<td>0.32</td>
<td>7.50</td>
<td>1.60</td>
<td>68</td>
<td></td>
<td>0.006</td>
<td>0.433</td>
<td>0.044</td>
<td>96</td>
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</tr>
</tbody>
</table>
Long-term data series are required to assess agricultural runoff pollution at different spatial scales. Agricultural emissions and retention processes of total N were studied in the Berze and Mellupite sites. The box and whisker plots are used in Figures 11 and 12 to illustrate total N concentrations and retention between study scales. In the

Figure 6 | Monthly minimum, 25th percentile, median, 75th percentile, maximum, outlier (○) and extreme (*) concentrations of total N, 1995–2009.
Berze site the highest concentrations of total N are observed in the drainage field scale; concentrations decrease when the scale of measurements increases (Figure 11). In the small catchment and Alave River total N concentrations decreased due to dilution and retention processes in streams, i.e. denitrification, organic matter storage in sediments, sediment sorption, and plant and microbial uptake, especially in the vegetation season. Extreme and outlying total N concentrations can be observed to be more frequent in plot and field scales rather than in small catchment and river scales due to vulnerability and a faster response to extreme meteorological and runoff conditions. In the Mellupite site the importance of retention processes on water quality are clearly demonstrated in Figure 12. The specific character of monitoring scales has to be taken into consideration when the analysis of water quality in different scales is performed. For example, runoff from the experimental plots can be considered as soil solution where the impact of retention processes is rather low.
Nutrient losses

The study showed that large temporal variations in total N and total P losses can occur and that, over years of monitoring, they are influenced by land management, farming practices and weather conditions. The results of nutrient losses are presented in Tables 3 and 4. In the Berze catchment N load ranged from 5.27 kg ha$^{-1}$ year$^{-1}$ in 2006 to 21.36 kg ha$^{-1}$ year$^{-1}$ in 2001. For the same study site and scale annual total, P load varies from 0.03 kg ha$^{-1}$ in 2006 to 0.52 kg ha$^{-1}$ in 1996. Generally, large temporal variations in annual losses are determined by the variations in annual discharge. It has also been found in small agricultural catchments in Norway, Estonia and Latvia by Deelstra et al. (2008). The above mentioned lowest N and P losses in the Berze catchment occurred in 2006 when the lowest annual site specific discharge (39.9 mm) was measured. The highest N loss in the Berze catchment was caused by the highest measured annual discharge (229.5 mm) in 2001. The highest P loss in 1996 was a result of very fast snow melts which generated soil erosion. The measured monthly discharge and losses in April were
139.3 mm and 0.44 kg ha$^{-1}$, respectively, which was 81% of the yearly discharge and 85% of the annual P load.

There was also large spatial variation in loads between study sites. During the study period the highest and lowest mean annual nutrient losses in the catchment scale were measured in Berze (e.g. 14.42 kg ha$^{-1}$ year$^{-1}$ of N and 0.19 kg ha$^{-1}$ year$^{-1}$ of P) and Vienziemite (e.g. 5.78 kg ha$^{-1}$ year$^{-1}$ of N and 0.11 kg ha$^{-1}$ year$^{-1}$ of P), respectively. Berze is located in the central part of Latvia with the most fertile soils where intensive and high nutrient input agricultural production is common, while Vienziemite is situated in northeast of Latvia, characterized as a representative area of low input agriculture. The changes in nutrient losses can be directly related to the nutrient balance, which often shows imbalance of the inputs to the soil system (fertilizers) with its normal outputs (high yields) in many farms of the Berze and Mellupite catchments. Studies in the field scale of Berze and Mellupite indicate that situation could be improved in the future if farmers are able to introduce better nutrient management practice; timing and rate of application of mineral and organic fertilizers and agricultural technologies promoting high yields (nutrient output). Poor handling of animal manure in farms could be the reason for the increase of nutrient content in surface and subsurface water. This situation has been noted and concluded from the interviews with farmers.

In general, in the drainage field scale, total N load are higher if arable land is the dominated land use type. For example, in the Mellupite site losses of total N in the drainage field was higher than in the small catchment. The exceptions monitored in the Berze site during 1999–2003 and in 2005 are related to higher annual discharge in the small catchment which resulted in higher losses of N. Generally, higher losses of total P in the catchment scale in the majority of the monitoring years may be explained by regular surface runoff and eroded material direct inflow in the open streams, which is the main pathway of total P transport, while surface runoff inflow in drainage systems via open inlets is rare and has occasional character. It should be mentioned that N and P losses in the Berze, Mellupite and Vienziemite small catchments are lower compared with similar agricultural catchments in central southern Sweden where leaching losses from arable land of 32 kg ha$^{-1}$ of total N and 0.31 kg ha$^{-1}$ of total P were estimated by Ulén et al. (2004).

### Nutrient standards

For EU member states, the overall aim of the WFD is to achieve ‘good ecological status’ and ‘good chemical status’ in all water bodies by 2015. The WFD suggest that member states develop scientific information concerning levels of nutrients that cause water quality problems. In Latvia the issue of water quality standards has not yet been implemented in legislation.
A water quality standard defines the goals for a water body by designating scientifically confirmed criteria to protect streams and establish control measures to improve existing water quality. In order to formulate water quality standards for drainage fields, small catchments and rivers influenced by agriculture, the method recommended by US Environmental Protection Agency (US EPA 2000) and the European Commission Joint Research Centre (Cardoso et al. 2001) was applied in this study. Agricultural runoff monitoring data collected in several scales during 1995–2009 could be used to define the criteria values for nutrients concentrations. Percentile selection of data plotted as probability distribution curves were used to establish boundaries of classes for water quality criteria. According to WFD, five classes of water quality could be designated using the following percentiles: (1) <10% excellent quality, (2) 10–25% good quality, (3) 25–75% fair quality; (4) 75–90% poor quality; and (5) >90% bad quality. Cumulative distribution and gamma curves of total N and total P concentrations at the catchment scale are illustrated in Figures 13 and 14. The joined data set of the Berze and Mellupite nutrient concentrations was used to define water quality standard criteria. Data from Vienziemite were not included because the site can be characterized as having low input agriculture reference conditions. Nutrient values for water quality criteria determined in this study are given in Table 5. Nutrient criteria numeric ranges, developed at the national level using existing databases of agricultural runoff monitoring, could be used to derive specific criterion values of water quality used to evaluate the success of control measures and action programme of ND.

### Table 3 | Total N losses (kg ha⁻¹ year⁻¹), 1995-2009

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</thead>
<tbody>
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<td>11.16</td>
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<td>5.82</td>
<td>5.55</td>
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<td>4.98</td>
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### Table 4 | Total P losses (kg ha⁻¹ year⁻¹), 1995-2009

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<td>Berze Small catchment</td>
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<td>0.19</td>
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<td>0.28</td>
<td>0.15</td>
<td>0.08</td>
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<td>0.14</td>
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<td>0.16</td>
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<tr>
<td>Drainage field</td>
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<td>0.04</td>
<td>0.08</td>
<td>0.10</td>
<td>0.13</td>
<td>0.08</td>
<td>0.16</td>
<td>0.09</td>
<td>0.08</td>
<td>0.16</td>
<td>0.20</td>
<td>0.11</td>
<td>0.11</td>
<td>0.10</td>
<td>0.07</td>
<td>0.11</td>
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</tbody>
</table>
Table 5 | Nutrient values for water quality criteria

<table>
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<tr>
<th>Quality class</th>
<th>Total N (mg L⁻¹)</th>
<th>Total P (mg L⁻¹)</th>
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<tbody>
<tr>
<td></td>
<td>Drainage field</td>
<td>Small catchment</td>
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<tr>
<td>Excellent</td>
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<tr>
<td>Good</td>
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<td>1.5–2.5</td>
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<tr>
<td>Fair</td>
<td>5.5–10.0</td>
<td>2.5–7.5</td>
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<td>Poor</td>
<td>10.0–12.0</td>
<td>7.5–10.5</td>
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<tr>
<td>Bad</td>
<td>&gt;12.0</td>
<td>&gt;10.5</td>
</tr>
</tbody>
</table>

Figure 13 | Cumulative probability distribution for total N concentrations.

Figure 14 | Cumulative probability distribution for total P concentrations.
CONCLUSIONS

The main conclusions are as follows:

- The results of the study indicate that concentrations of total N vary in all study sites following the seasonal fluctuations of water discharge. In small catchment and drainage field scales, higher mean concentrations of total N were observed in Berze compared with the Mellupite and Vienziemite sites. The variations in total P concentrations are related to the large impact of occasional surface runoff events that promote P transport from soil to water.
- The concentrations of total N in agricultural areas depend on the spatial scale of measurements. In general, concentrations decrease when the scale of measurements increases. For example, in the Berze site higher concentrations of total N were found in the drainage field scale and these decreased in the small catchment and river scale. The variation in concentrations can be explained by different conditions for retention processes within spatial scales, e.g. denitrification, organic matter storage in sediments, sediment sorption, and plant and microbial uptake.
- The study showed that compared with intensively farmed area in the Berze site the nutrient losses were lower in the Mellupite and Vienziemite sites. Increased losses of total N and total P in Berze are caused by substantially higher mineral and organic fertilizer application rates, which often exceed the needs of agricultural crops.
- Long-term agricultural runoff monitoring data can be useful to develop scientifically based criteria for water quality assessment.
- The important finding of the research is that water quality standards for nitrogen in the drainage water, as well as for small catchments with intensive agriculture, should be less stringent than for rivers, otherwise it will not be possible to fulfill the objectives – good water quality status in 2015, set by the WFD. Recommended classification for values of the nutrient quality status could be used for the purpose of monitoring and evaluation agro environment measures of Rural Development Plan in Latvia.

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