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Nitrogen load assessment and pollution mitigation measures in the Dovinė watershed

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Assessment of diffuse nitrogen pollution in the Dovinė watershed is performed by analysing agricultural activity in the Dovinė watershed and applying nitrogen leaching coefficients determined in the watershed analogues where comprehensive monitoring is performed. In the Dovinė watershed, the determined total nitrogen load makes up 473.8 tonnes per year. Nitrogen leaching due to farming activity is 5.56 kg N ha^{-1}.

In the paper, there are presented nitrogen leaching mitigation measures, which are most reasonable for southern Lithuania. The most effective measures are the ones that could be applied on a bigger part of the watershed, e. g., balanced fertilisation would reduce nitrogen load by 7.95%, reduced soil tillage by 16.6%. The total effectiveness of all the discussed measures for the entire watershed is 36.4%.

Key words: watershed, nitrogen, mitigation measures, load calculation, arable lands

INTRODUCTION

Agricultural practice, including intensive livestock husbandry, is one of the main contributors to the high nutrient load to aquatic ecosystems. In many European catchments, nitrogen load from agriculture represents the greatest source of groundwater and surface water pollution (Kronvang et al., 1996; Behrendt et al., 2002). Protection of water bodies from pollution by main nutrients originating in agricultural fields is one of the most demanding environmental tasks. Land use factors such as fertilization, area of arable land and ploughing, were found to have profound effects on the quantity of nutrients leached from soil (Burt, Haycock, 1993; Vinten, Smith, 1993). Grassland, if grazed not intensively, is less prone to N leaching than arable land (Kolenbrander, 1981; Gustafson, 1987; Kutra et al., 2002). The concentration of mineral N found by Kutra et al. (2002) was 3.5 mg l^{-1} in the drainage water from fields of perennial grasses and 11 mg l^{-1} in the drainage water from arable fields when most of the subsurface drainage systems were investigated in the Graisupis catchment. Our later investigations (Kutra et al., 2006) of nutrient leaching revealed that the largest quantities of nitrogen were leached from fields under row crops (22.4 kg ha^{-1} $year^{-1}$). Nitrogen leaching from fields under spring and winter cereals was 18.9 and 16.5 kg ha^{-1} $year^{-1}$, respectively. The level of leaching was lowest from fields under pastures (10.5 kg ha^{-1} $year^{-1}$). Long-term investigations (1972–1995) of the migration of chemical elements in the soil–water–plant, system using a more accurate (if compared to field trials) lysimetric method, revealed the following average amounts of nutrients washed out from soil: 31–51 kg ha^{-1} $year^{-1}$ of nitrogen, 9–27 kg ha^{-1} $year^{-1}$ of potassium and 1 kg ha^{-1} $year^{-1}$ of phosphorus (Vaičys et al., 1998). In about 38% of the water samples from dug wells in Lithuania, the concentration of nitrates reached 50 to 200 mg l^{-1} (Juodkazis, Kučingis, 1999).

Degradation of water quality is the major health concern for lakes and reservoirs of the United States as a result of heavily devoted agricultural production (Wang et al., 2005).

Farming methods for improved nitrogen management have to be developed to reduce nitrate leaching from agricultural fields (Boesch et al., 2001; Oenema, Velthof, 2000; Sileika et al., 2000).

River management policy requires a scientific input that is both unequivocal and authoritative. Management practices to improve water quality must be designed in accordance with the dominant problems and transport pathways of a watershed (Blanchard, Lerch, 2000). It should be a good background for a more detailed planning of measures for preventing leaching on the farm, community and watershed level.

The objective of our applied studies was to analyse the non-point pollution level in the Dovinė river watershed and to present options for measures and farming practices that could lead to mitigation of nutrient leaching.

MATERIALS AND METHODS

Characteristics of the Dovinė watershed and land use

The area of the Dovinė river watershed is about 58.7 thousand ha. The Dovinė river watershed was divided into two parts: the watershed upstream Lake Žuvintas (its area is about 32 thousand ha) and the watershed downstream Lake Žuvintas (26.7 thousand ha).

The Dovinė river watershed is situated in the territory of four municipalities – Marijampolė, Alytus district, Lazdijai district and Prienai district – and their communities Simnas, Igliauka, Gudeliai, Liudvinavas, Krosna, Marijampolė, Naujoji Ūta, Seirijai, Šeštokai, Šilavotas, Šlavantai, Šventežeris and Teizai. The main economic activity in the region is agriculture.

Calculations on the basis of GIS maps showed that the area of cultivated land in the Dovinė watershed is 270.2 km^2 and makes 45% of the total area (Fig. 1). The rest of the territory is occupied by meadows and pastures (16%), forests (12%), water bodies (8%), built-up areas (3%), and peat bogs and marshes (15%).

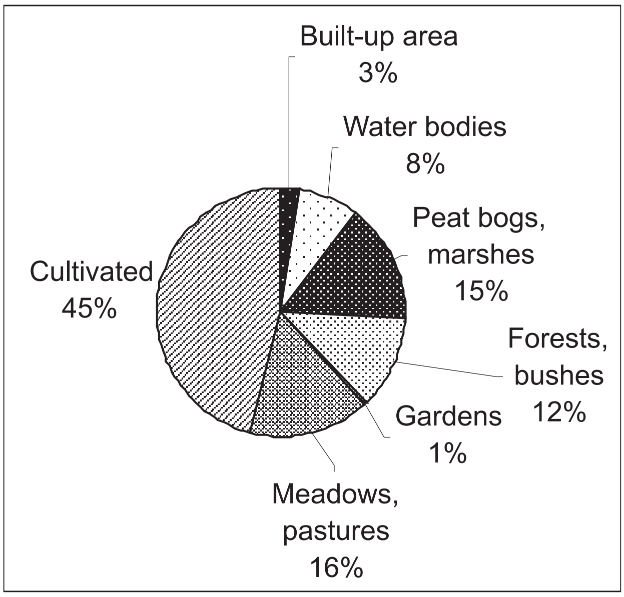

Fig. 1. Distribution of lands in the Dovinė watershed

Soil agrochemical, physical and farming properties are comparably good in the Dovinė watershed. The dominant soils are Haplic Luvisols covering one third of the basin. Gleyic Luvisols cover more than 20% of the watershed territory. Soil distribution according to texture is as follows: 27.9% of sandy loam, 26.5% of peat and 20.7% of light clay loam. Sandy loam soils prevail in the hilly southern part of the basin, light clay loam and peat soils dominate within the Žuvintas Biosphere Reserve (Kitnaes et al., 2006). In the Dovinė watershed, acidic soils (pH 5.5 and lower) constitute 10.7–29.9% of all soils. Soils with a low and very low content of phosphorus (P_2O_5) make up 42.5–69.3%, and of potassium (K_2O) 22.1–35.2% of the watershed area (Mazvila et al., 1998).

The relative area of cultivated land increases to 50.5% in the Dovinė watershed downstream Lake Žuvintas as compared to the territory upstream Žuvintas (42.4%). Downstream Žuvintas there are more meadows and pastures (17.6% versus 13.9% upstream Žuvintas), therefore the total area used for agriculture is larger by 11.8%. Downstream Žuvintas there are less water bodies – 1.1% (13% upstream Žuvintas); there are less marshes and peat bogs – 13.3% (17.6% upstream Žuvintas). Among the natural land use types, there are slightly more forests and bushes (13.7% and 10.7%, respectively).

The natural watershed borderline does not follow the administrative borders of the communities. Only a small part of some communities fall within the borders of the Dovinė watershed (e. g., 56 ha of the Seirijai community). Data on land use were available only on generalised community level. Therefore an arithmetic mean (by communities, assuming that the communities have equal weight) and a weighted mean (weighted by community area within the watershed) were calculated for the area of each land use type. 0 shows that in the Dovinė watershed upstream Žuvintas the difference between the arithmetic mean and the weighted mean (the latter represents the actual situation) is from 0 to 90%, i.e. 20% for cultivated land, 60% for marshes and peat bogs, 55% for forests and bushes and 90% for the built-up area. Downstream Žuvintas the differences are slightly smaller: 14% for cultivated land, 41% for marshes and peat bogs, 40% for gardens and 14% for forests and bushes. The analysis shows that to ascertain the actual situation it is not enough to calculate the arithmetic means of a few randomly chosen economic entities.

Data on crop area and animal number declared by farmers, as well as data of land survey services and data received during questioning of farmers were used for crop structure analysis and for elaboration of mitigation measures.

Crop structure analysis was performed by distributing the crops into seven groups: meadows and pastures, winter crops, spring cereals, spring leguminous, row crops, perennial grasses and set-aside land. Mean values of the crop area in communities, extreme values (minimum and maximum) and standard errors were determined.

Farms of each community were grouped into three groups according to the number of declared animals. The first group comprised farms that keep less than 10 animal units (AU), the second – between 10 and 300 AU, the third – more than 300 AU. LAND 33-99[1] and the project of LAND 33-2004[2] state that 1 AU is equal to 1 milking cow or 3 heifers (from 1 year) or 5 calves (to 1 year) or 2 beef cattle to 2 years of age or 8 sucker pigs or 2 horses or 9 sheep or goats. The data received from the Centre of Agricultural Information and Rural Business contained information only about the total number of cattle (not indicating their age), therefore we considered 1 AU equal 2 cattle.

Calculations of nitrogen leaching

Land use was considered an important factor determining the scale of nutrient leaching and pollution of Lake Žuvintas (national reserve) and of other water bodies.

[1] Lietuvos Respublikos Aplinkos ministro įsakymas "Dėl mėšlo ir nuotėkų tvarkymo fermose aplinkos apsaugos reikalavimų (LAND 33-99) patvirtinimo" 1999 m. gruodžio 27 d. Nr. 426. Valstybės žinios, 2000, Nr. 8-217.

[2] Lietuvos Respublikos Aplinkos ministro įsakymo "Dėl mėšlo ir nuotėkų tvarkymo fermose aplinkos apsaugos reikalavimų (LAND 33-2004) patvirtinimo" projektas.

Table 1. **Crop structure in the Dovinė watershed**

Parameter	Crops, %						
	Set-aside land	Meadows, pastures	Winter crops	Spring cereals	Spring leguminous	Row crops	Perennial grasses
Mean	4.7	3.5	23.4	23.3	4.6	7.9	32.5
Min–max	1.9–11.3	0.5–8.1	11.8–32	15.6–30.6	1.1–9.8	2.2–18.1	17.6–43
Standard error	±51.2	±83.6	±32	±19	±66.8	±63.8	±28.1
Share (%) in the total area	4.8	2.6	23.9	23.5	6.4	9.3	29.4
Share (%) upstream Žuvintas	4.3	4.6	16.7	28.5	6.1	9.2	30.5
Share (%) downstream Žuvintas	5.2	1.2	28.9	20.1	6.5	9.4	28.7

The analogue approach was used for nutrient leaching calculations in the Dovinė watershed. Conversion coefficients were prepared using monitoring data of nutrient leaching in agrostationars of the watersheds with similar soil and land use conditions: the Graisupis river watershed (Lithuanian Middle Plain, Kėdainai district) and the Vardas river watershed (south-eastern hilly laky highland, Ukmergė district). In the Graisupis watershed, the majority of soils are loam (57%) and sandy loam (40%), neutral, saturated with phosphorus and rather poor of potassium. In the Vardas watershed, the dominant soils are loamy sand (71%) and peat (15%), slightly acidic, poor of phosphorus and having a medium content of potassium. A detailed description of the Graisupis and Vardas watersheds can be found elsewhere (Gaigalis et al., 2004; Sileika et al., 2005).

Every year the crops grown on most of the fields of the Graisupis watershed in 2000–2004 were registered. Data on nitrogen leaching from fields under winter crops, spring crops and row crops (summarised as arable lands), from pasture and from the territories of farmstead were obtained by measuring the concentrations in about 50 drainage systems in spring annually in the Graisupis demonstration watershed (Gaigalis et al., 2004). Thee mean concentration for each group of crops and standard errors were calculated according to the crops grown on drained fields. Total nitrogen (N) in water was determined by the photometric method using phenoldisulphoacid and potassium peroxodisulphate after oxidation[3]. Nitrogen concentration in the water from arable fields was 10.7, from pasture 4.6, from the territory of farmsteads 16.6 mg l^{-1}.

According to soil characteristics (the share of peaty soils in the watershed) and the intensity of farming activity, the Dovinė watershed (especially upstream Žuvintas) is more similar to the Vardas watershed than to the Graisupis watershed. Therefore, for the calculations of nutrient losses from agricultural area we used nitrogen concentrations corresponding to the Vardas river: 7.8 mg l^{-1} for arable land, 3.6 mg l^{-1} for ley, and 16.6 mg l^{-1} for the territory of farmsteads. Nitrogen losses from forested areas were calculated according to the mean values of the analysis performed in the Graisupis watershed for many years – 1.5 mg l^{-1} (Gaigalis et al., 2004). Nitrogen concentration in the water coming from set-aside areas was considered as a background load. We used long-term mean specific water runoff of 5.7 l s^{-1} km^{-2} in the Dovinė river for calculating annual water runoff and nutrient load (Gailiušis et al., 2001).

We performed investigations in the Bariūnai agricultural company in Joniškis district in order to determine the impact of a cattle barn on nitrogen leaching. The measurement of concentrations and the calculation of nutrient leaching from the territory of the barn gave the following result: 0.49 kg of total nitrogen leached for 1 animal unit (AU) per year on average.

Pollution mitigation measures

Farming practices for separate communities of the Dovinė watershed were analysed from the environmental point of view. Measures for mitigation of the nutrient leaching were proposed. The following nitrogen leaching coefficients were used to calculate reduction in leaching if one crop would be substituted by another crop: 10.5 kg N ha^{-1} for perennial grasses, 16.5 for winter grain crops, 18.9 for summer grain crops, and 22.4 kg N ha^{-1} for row crops (Kutra et al., in press). Results from our earlier investigations (Kutra et al., 1996; Kutra and Račkauskaitė, 2001; Aksomaitienė et al., 2002; Kutra and Aksomaitienė, 2003; Baigys et al., in press) were used to evaluate leaching reduction for the mitigation measures other than changes in crop rotation. The effectiveness of each measure for the entire watershed was calculated according to the reduction of leaching for a watershed area unit and the area of the watershed where the proposed mitigation measure should be applied.

RESULTS AND DISCUSSION

Crop structure in the communities of the Dovinė watershed is presented in Table 1. The relative area of perennial grasses (29.4%) in the crop structure is sufficient: it has to be no less than 20% according to the Code of Good Agricultural Practice[4] (CGAP). In separate communities the area of perennial grasses could be larger, because in some communities it is either less than 20% (17.6% in

[3] Lietuvos Respublikos Aplinkos Ministerija. Unifikuoti nuotekų ir paviršinių vandenų kokybės tyrimų metodai. Vilnius, 1994.

[4] Ministry of Agriculture of the Republic of Lithuania, Ministry of Environment of the Republic of Lithuania. Code of Good Agricultural Practice. Kedainiai, Vilainiai. 2000.

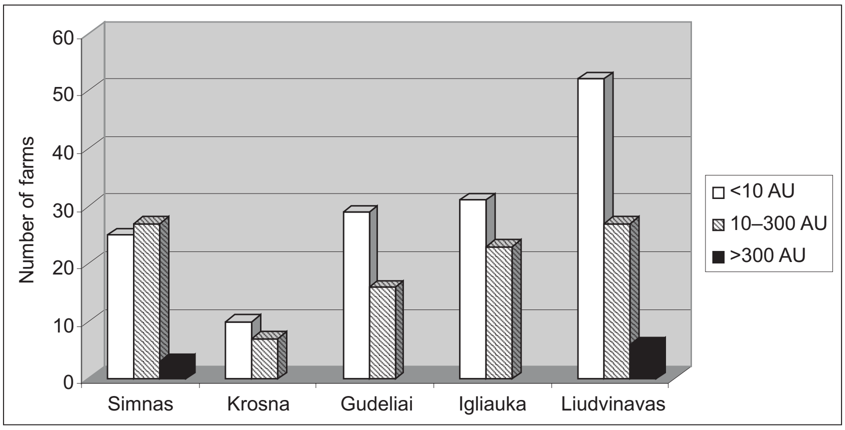

Fig. 2. Distribution of farms according to the number of animal units (AU) in the communities of the Dovinė watershed

Table 2. **Nitrogen load to the Dovinė river from different areas**

Land use	Area, km²	Water discharge, thousand m³	Concentration, mg l⁻¹	Load, kg
Nitrogen from the area **upstream Žuvintas** (watershed area 345 km² including water bodies)				
Arable	101.8	18302	7.8	142756
Ley	97.9	17605	3.6	63378
Built-up area	7.2	1302	16.6	21619
Forests and marshes	93.2	16744	1.5	25116
Load increase due to animals (6845 AU × 0.49 kg)				3354
Total				256223
Nitrogen from the area **downstream Žuvintas** (watershed area 244 km²)				
Arable	85.41	15353	7.8	119753
Ley	78.80	14165	3.6	50993
Built-up area	7.81	1404	16.6	23305
Forests and marshes	69.30	12457	1.5	18686
Load increase due to animals (9860 AU × 0.49 kg)				4831
Total				217567

Simnas) or slightly more (21.1% in Liudvinavas) than CGAP recommends. If the mean value is only 20%, then at a normal distribution the area of perennial grasses is less than 20% in 50% of the farms.

Analysis of the crops structure shows also that the mean areas of the crops are sufficient to make crop rotation with a proper fore-crop for spring cereals (row crops, leguminous spring cereals, winter crops) and good fore-crops for winter cereals (set-aside land, perennial grasses, leguminous, and early potatoes).

Crop structure in the communities upstream Žuvintas was compared with crop structure in the communities downstream Žuvintas (Table 1). The percentage of perennial grasses was lower downstream Žuvintas (28.7%), and higher (30.5%) upstream Žuvintas. Upstream Žuvintas there are grown more spring crops (28.5%) and less winter crops (16.7%), versus 28.9% of winter cereals and 20.1% of spring crops in the total crop area downstream Žuvintas.

Summarising the results of the crop structure analysis in the Dovinė watershed, we can state that the requirements raised by the EU Nitrate Directive[5] and objectified by the CGAP are not violated in the Dovinė watershed. Only separate farms specialise in growing cereals and, as our questionnaire results show, sow a small area of perennial grasses or do not sow grasses at all and in such a way violate the environmental requirements.

Environmental problems of animal breeding farms are mostly related to the management of manure and slurry, especially as most of the farms have not constructed manure storages.

Small farms dominate in most of the communities of the Dovinė watershed (Fig. 2). Of 260 farms that have declared the animals, 113 farms, i. e. 43.5%, have more than 10 AU. Thirteen farms have more than 300 AU, two of them are pig farms, the rest being diary and beef cattle farms.

The results of land use and animal density analysis were used for estimation of nitrogen leaching in the watershed and quantification of nitrogen inputs to the Dovinė river and its tributaries.

In the Dovinė watershed, we calculated the nutrient load from arable fields and forest and also nutrient load in proportion to the animal number in the watershed. The mean nutrient load is 8.04 kg of nitrogen per 1 ha of the watershed area. The total amount of nitrogen that reaches the water bodies is 473.8 tonnes. The background load makes up 146 tonnes of nitrogen. The amount of nitrogen that reaches the Dovinė watershed due to farming activity (not including background leaching) makes 5.56 kg ha^{-1}.

The total nitrogen load is bigger in the Dovinė watershed upstream Lake Žuvintas (256.2 tonnes). Downstream

[5] EU Council Directive concerning the protection of waters against pollution caused by nitrates from agricultural sector (91/676/EEC).

Žuvintas, the corresponding load is 217.6 tonnes (Table 2). Downstream Lake Žuvintas the cultivated lands make up a relatively bigger part, besides, there are more animals on the farms; therefore, more nitrogen leaches per 1 ha of the watershed area downstream Žuvintas (8.92, or 6.25 without background leaching). The corresponding numbers were 7.33 kg N ha^{-1} (5.08) for the watershed upstream Žuvintas.

Nitrogen pollution mitigation measures

Implementation of environmentally sound farming practices in the watershed can reduce river pollution. The effectiveness of the measures was determined by calculating nitrogen leaching in the watershed when crop structure or farming practices are changed on a certain area of the watershed. In Table 3 we present some measures that we believe to be most perspective and applicable for the Dovinė watershed and similar territories of southern Lithuania.

As was stated above, the mean crop structure in the Dovinė watershed complies with the requirements of the CGAP, but not in separate communities and farms. Increasing the areas of perennial grasses as we recommended in the Graisupis watershed (Kėdainiai district) of intensive farming (Kutra et al., in press) can be used on some farms specializing in plant production in the Dovinė watershed as well. In some communities of the Dovinė watershed (e. g., Krosna, Liudvinavas), the area of sugar beet crops is twice as big as the average in the watershed. Nitrogen leaching will decrease if row crops (sugar beets) are substituted by winter rape crops (measure A).

Balanced fertilization as a mitigation measure B is proposed according to the results of our earlier investigations (Kutra et al., 1996; Kutra and Račkauskaitė, 2001; Aksomaitienė et al., 2002; Kutra and Aksomaitienė, 2003). Misbalanced use of P and K fertilizers is one of the factors leading to increased nutrients surplus in soil. According to Aksomaitienė et al. (2003), leaching of nitrogen (y) depends on N content in the soil (x_1) and on fertilization (x_2) by the following relationships: $y = 0.26x_1 + 3.4$ ($R^2 = 0.68$), $y = 14.57 - 0.061x_2 + 0.00058x_2^2$ ($R^2 = 0.74$). The effectiveness of nutrient leaching for this measure is approximated to 10%.

When saving energy resources and reducing labour expenses, the measures such as minimized soil tillage (measure C) become more popular. Moreover, our investigations show that they lead to a reduced nutrient leaching. As a result of a 5-year rotation experiment, nitrogen leaching from fields of conventional tillage was 148 kg ha^{-1}; the leaching from fields of minimized tillage (using a disc cultivator) was 103 kg ha^{-1}; and when ploughing with a mouldboard plough was performed in late autumn (before freezing in November) the leaching was 98 kg ha^{-1}. The approximated leaching decrease was 30% (Baigys et al., in press).

Measure D should be implemented fulfilling requirements of the EU Nitrate Directive: construction of manure and urine storage facilities, improved technologies of manure spreading and timing. Measure E is effective from the environmental point of view, i. e. set-aside fields can be used for establishment of forests in arable lands. The effectiveness of D and E measures is the highest and reaches 78% and 81%.

Total reduction in nitrogen leaching could reach 36.4% if all the proposed measures would be applied in the watershed. Total annual nitrogen runoff would decrease by 172.4 tonnes. A similar study performed in Sweden showed that nitrogen leaching could be reduced by 34% to 54% for separate catchments if the following measures were implemented: application of manure in spring instead of autumn; postponed ploughing-in of ley and green fallow in autumn; undersowing a catch crop in cereals and oilseeds; and increasing the area of catch crops by substituting winter cereals and winter oilseeds with corresponding spring crops (Kyllmar et al., 2005).

The effectiveness of the proposed mitigation measures should be elaborated further because they have been investigated on a plot level only. With the measures applied in at least a few watersheds, the estimations will be further improved.

CONCLUSIONS

The analogue approach and the analysis of nutrient leaching in the Dovinė watershed have shown that the land use data are a good background for calculation of nitrogen inputs to the river and other water bodies and for planning the measures to reduce leaching. The input of nitrogen is highest from the areas located close to animal farms and from intensively managed arable lands, especially row crop fields. Statistical data on land use and animal number for communities may be used for nitrogen leaching calculations.

The most effective measures for pollution mitigation are those that can be applied on a bigger part of the watershed, such as balanced fertilization (decrease of N load in the watershed by 7.95%), reduced soil tillage (decrease 16.6%). Such an effective measure as planting of forests

Table 3. **Measures for mitigation of nitrogen leaching in the Dovinė watershed**

Measures	Area of application, ha	Effect on the area of use, %	Effect on the watershed, %	Decrease of N leaching, kg
A. Decrease of row crops area by 50% (substituted by winter rape)	1700	26.8	2.2	10 200
B. Analysis of plant-available P and K and balanced fertilisation	36391	10	7.95	37 688
C. Reduced soil tillage	18721	30	16.6	78 750
D. Improved manure maintenance on farm and settlement territories	1500	78.35	7.43	35 200
E. Afforestation of 5% of arable (set-aside) land	936	80.78	2.24	10600
Total			36.4	172438

on arable lands (decrease of pollution by 81% in the area of implementation) is not suitable in larger areas; therefore its effectiveness for the watershed is only 2.2%.

Utilization of animal manure is especially problematic for big farms which keep a lot of animals (above 300 AU). In such a vulnerable region as the Dovinė watershed, the calculation of animal number is very important from both the economic and environmental points of view. If all requirements of safe manure handling are implemented on the farms, then nitrogen leaching from the grasslands, even close to farms, will not be higher than from pasture fields. The decrease of pollution, as our calculations show, will reach 78% on the spot and 7.4% in the entire watershed.

Mitigation of pollution by nitrogen in the Dovinė watershed after implementation of all the recommended measures will comprise 172.4 tonnes N year^{-1}, or 36.4% for the entire watershed.

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AZOTO IŠPLOVIMO ĮVERTINIMAS IR TARŠOS MAŽINIMO PRIEMONĖS DOVINĖS BASEINE

Santrauka

Pasklidoji azoto tarša Dovinės upės baseine buvo įvertinta panaudojant azoto išplovimo koeficientus, nustatytus baseinuose analoguose, kuriuose atliekami stacionarūs stebėjimai, bei Dovinės baseino žemės ūkio veiklos išsamios analizės rezultatus. Nustatytas bendras azoto išplovos kiekis Dovinės baseine sudaro 473,8 t per metus. Azoto išplovimas dėl ūkinės veiklos yra 5,56 kg N ha^{-1}.

Straipsnyje aptartos azoto išplovimo mažinimo priemonės, priimtiniausias Pietų Lietuvos sąlygomis. Efektyviausios yra tos priemonės, kurios gali būti taikomos kuo didesnėje baseino dalyje, pvz., subalansuotas tręšimas sumažintų išplovą 7,95%, sumažintas žemės dirbimas – 16,6%. Bendras aptartų priemonių efektyvumas visam baseinui yra 36,4%.

Raktažodžiai: upelio baseinas, azotas, apsaugos priemonės, išplovos skaičiavimas, dirbamos žemės