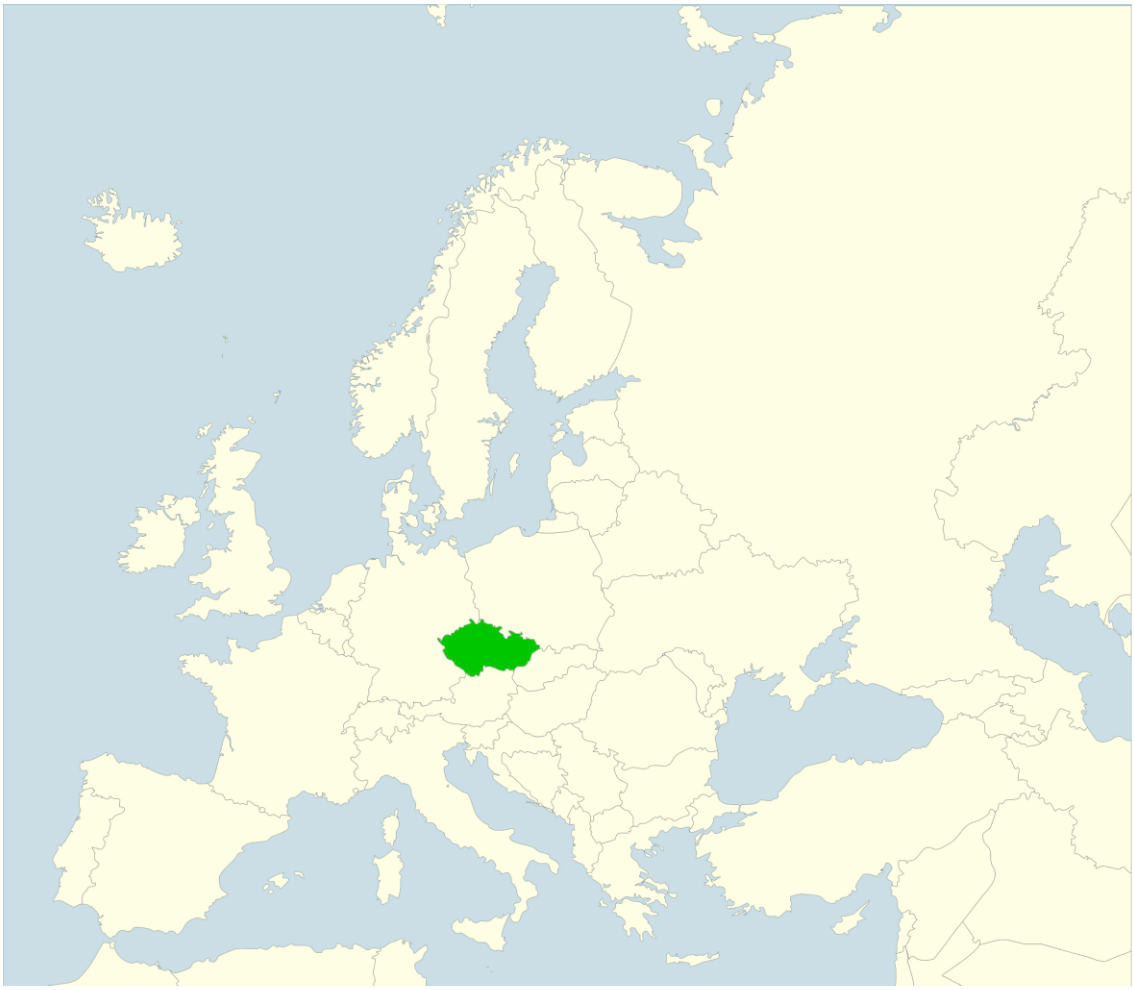
Europ. Countrys. · 1 · 2017 · p. 17-28
DOI: 10.1515/euco-2017-0002

European Countryside MENDELU

INTEGRATION OF SOIL AND WATER CONSERVATION MEASURES IN AN INTENSIVELY CULTIVATED WATERSHED – A CASE STUDY OF JIHLAVA RIVER BASIN (CZECH REPUBLIC)

Jana Konečná[1], Petr Karásek[1], Petr Fučík[2], Jana Podhrázská[1], Michal Pochop[1], Stanislav Ryšavý[3], Roman Hanák[3]



[1] Ing. Jana Konečná, Ph.D., Mgr. Petr Karásek, Doc. Ing. Jana Podhrázská, Ph.D., Ing. Michal Pochop, Research Institute for Soil and Water Conservation, Department of Land Consolidations and Landscape Use, Lidická 25/27, 602 00 Brno, Czechia; tel.: +420 541 126 281, konecna.jana@vumop.cz

[2] Ing. Petr Fučík, Ph.D., Research Institute for Soil and Water Conservation, Žabovřeská 250, 156 27 Prague, Czechia

[3] Ing. Stanislav Ryšavý, Ing. Roman Hanák, AQUATIS, a.s., Botanická 834, 602 00 Brno, Czechia

Received 12 May 2016; Accepted 26 September 2016

Abstract: Reduction of nitrogen and phosphorus inputs into surface waters from nonpoint agricultural sources requires targeted application of differentiated measures. In the study focused on soil and water conservation in the Jihlava river basin upstream of the Dalešice reservoir, we identified areas at potential risk of soil erosion, elevated infiltration and nutrient leaching, tile-drained areas and vulnerable riparian zones of water bodies. We then designed a system of complex protective measures for this river basin in more variants, and their effectiveness was estimated using simple empirical model calculations and research findings. Application of the measures defined by optimal variant 3 in the studied watershed could lead to reduction of the soil erosion effects on the surface water quality by 26.5%, with simultaneous reduction of the amount of washed out total nitrogen by 22.8%. The results of our study constitute a partial component of the Qualitative Model of the Jihlava River Basin and they were provided for use to the Vysočina Region authorities and the State Land Office.

Keywords: Dalešice reservoir; non-point agricultural pollution; nitrogen; phosphorus; soil erosion; nutrient leaching; protective measures.

Abstrakt: Snížení vstupů dusíku a fosforu do povrchových vod z plošných zemědělských zdrojů vyžaduje cílené uplatňování diferencovaných opatření. V rámci studie zaměřené na ochranu půdy a vody v povodí Jihlavy nad vodním dílem Dalešice byly identifikovány oblasti s potenciálním rizikem vodní eroze, zrychlené infiltrace a vyplavování živin, odvodněné plochy a ohrožené příbřežní zóny vodních útvarů. Následně byl pro toto povodí navržen systém komplexních opatření ve více variantách a jejich účinnost byla odhadnuta pomocí jednoduchých empirických modelových výpočtů a na základě výzkumných poznatků. Realizace opatření obsažených v optimální variantě 3 by mohla v zájmovém povodí vést k omezení dopadů vodní eroze na kvalitu povrchových vod o 26,5%, současně se snížením objemu vyplavovaného celkového dusíku o 22,8%. Výsledky studie jsou dílčí součástí Jakostního modelu povodí Jihlavy a byly poskytnuty k využití Kraji Vysočina a Státnímu pozemkovému úřadu.

Klíčová slova: vodní nádrž Dalešice; plošné zemědělské znečištění; dusík; fosfor; vodní eroze; vyplavování živin; ochranná opatření.

---

1. Introduction

The potential negative impacts of continuing climatic changes on water sources attract attention of both scientists and policy makers worldwide. Their manifestation in the territory of the Czech Republic is twofold – the growing occurrence and intensity of extreme precipitation brings about damage to the soil by water erosion. Consequently, the erosion products pollute water courses and reservoirs and influence negatively the quality of surface water. Data from monitoring of meteorological characteristics along with model calculations (Trnka et al. 2011) show that due to the climatic changes, the territory of Central Europe and also the Czech Republic will probably experience more frequent droughts, as a consequence of precipitation deficit as well as of the constant rise in air temperature and evaporation. These phenomena will not only affect the quantity of water in the landscape, but its quality as well. Should contamination produced by both point and nonpoint pollution sources not be actively limited, concentrations of nutrients and risk compounds will continue growing.

The nonpoint sources of potential agricultural pollution of surface water include blocks of agricultural land situated in the immediate proximity of water body banks, slopes of arable land at risk of erosion, localities at risk of accelerated infiltration and nutrient leaching, and areas of arable land connected to land drainage systems. The highest risk of soil erosion causing water pollution is experienced in steep slopes or long field blocks hydrologically connected to water courses. The eroded material has fine-grain structure and is enriched in nutrients (Janeček et al. 2012). Its transport into surface water results in contamination and silting of water bodies. In most cases, soil erosion is quantified using the 'universal soil loss equation', as reported by Janeček et al. (2012) or Panagos et al. (2015), complemented by the corresponding values of factors. However, not all eroded soil reaches the water courses. To express the transportation and sedimentation processes in the catchment, one can use the ratio of soil loss or the mathematical transportation model (e.g. WaTEM/SEDEM). The properties of the products of soil erosion that are found in water courses or reservoirs differ from those of the original soil material, including the phosphorus and nitrogen content and forms. Although this issue was addressed e.g. by Novotny and Chesters (1989), Sharpley (1985), or Tesfahunegn & Vlek (2014), the rate of sediment enrichment by phosphorus and nitrogen as well as the processes of release of these compounds into water have not yet been adequately clarified.

Nitrogen and nitrates represent the main products of nonpoint agricultural pollution in water. Many research teams both in the Czech Republic and abroad (e.g., Köhler, Duynisveld & Böttcher 2006, Laurent & Ruelland 2011) focus their research upon investigating the processes and factors responsible for this phenomenon. Due to the complexity of this process, the approaches for diminishing nitrogen washing out from the soil to water have not yet been adequately established. Research focused on nitrogen leaching from arable land attempts to find potential ways to reduce fertilization, use intercrops or winter crops and changes in land parcel types, promote changes in agro-technology (tillage) in selected catchment zones, or use combination of these techniques while maintaining crop yields. In general, there is a significant seasonal and inter-annual variability in the nitrogen leaching, with the main determining factors represented by the weather course (precipitation, temperature, soil moisture), accumulated nitrogen content in the soil, and intensity of its mineralization (Bauwe et al. 2015, Fučík et al. 2012). Fučík, Novák & Žížala (2014) and Fučík et al. (2015) have shown that nitrogen leaching from agricultural land can be reduced by targeted grassing in the areas at risk of accelerated infiltration.

The nonpoint pollution sources are difficult to manage and control due to a complicated formation and nature (Li at al. 2016). Despite intensive monitoring, data on the ecological condition of water courses, defined by the EC Framework Water Directive as a complex of chemical, biological and hydro-morphological properties of surface water, are still limited in CR and also whole Europe. Only modest improvement of water quality and ecological condition of water courses that is observed in spite of the large investments into this area (Gilbert, 2015) is a result of the long-lasting imbalance between application of the protective measures to water courses of varying quantitative categories and underestimation of synergies in application of particular interventions to the environment of water courses at their particular spatial levels.

Our report brings partial results of the study of soil and water conservation in the Jihlava river basin, elaborated (2012–2013) as a part of a complex project (Ryšavý et al. 2013) aimed at designing a system of measures for preservation and potential improvement of water quality in water plant Dalešice. This paper presents analysis of the sources of nonpoint agricultural pollution in the catchments, principles of joint soil and water conservation, and results of efficiency evaluation of designed measures aiming to reduce soil erosion and nitrogen leaching from intensively cultivated land.

The study locality in the Jihlava river basin is situated above the Dalešice water plant (surface area 1155 km^2) with closure at the dam near Mohelno town (Fig. 1). It lies in the Bohemian-Moravian Highlands, and its landscape is thus undulated, divided by protracted ridges and valleys, with numerous forests (32% area), groves, meadows and pastures. At present, this landscape is intensively cultivated. Agricultural land covers 50% of the catchment surface, with 37% of arable land and 13% of permanent grasslands (Fig. 2). For the purposes of the qualitative model prepared by AQUATIS company, the investigated Jihlava river basin was divided into 122 subcatchments, at the closures of which the nitrogen and phosphorus inputs from both point and nonpoint sources were assessed.

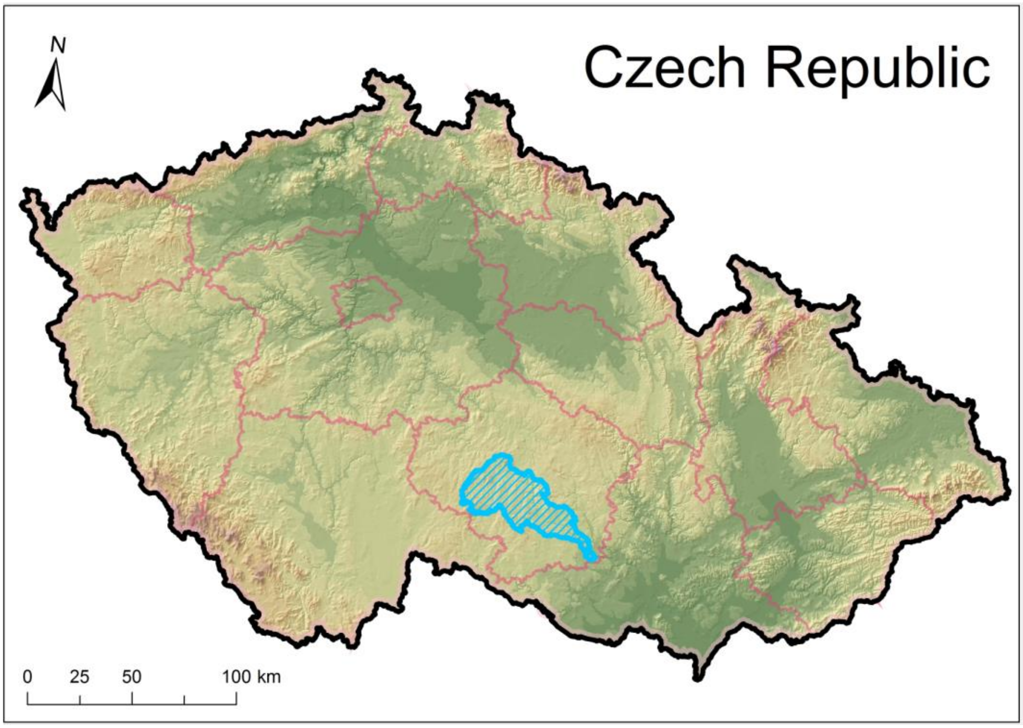


Fig 1. Localization of the studied catchment (blue colour).

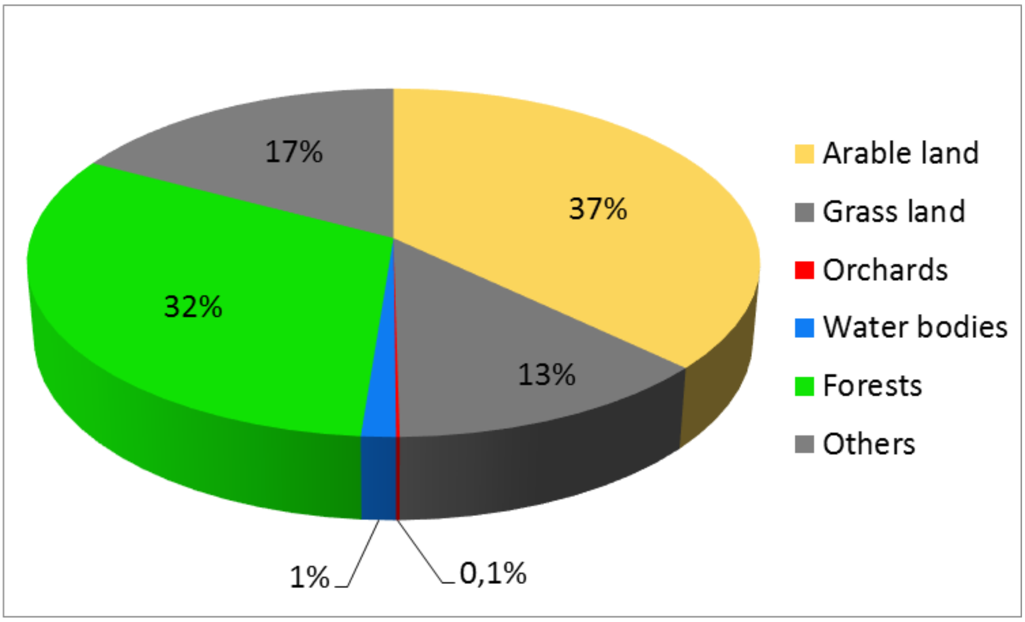


Fig 2. Land use in the studied catchment.

Soil conditions are given by geological and climatic factors and by the nature of the terrain relief. As the locality is situated in uplands, the prevailing soil types are Cambisols of various subtypes (modal, gleyed, dystric, etc.), covering 77% of agricultural land. Cryptopodsols have evolved at higher altitudes. The mosaic of the soil cover is mainly complemented by Pseudogleys, Luvisols, and Gleys. The texture types are represented by sandy-loams interspersed with loams. The prevailing substrates are acid and mesobasic crystalline rocks. The model catchment includes a total of 7473 ha of shallow soils (in the subgroup of Cambisols and Cryptopodsols). Of these, 5884 ha are cultivated land parcels (i.e., 10% of the total agricultural land). The mean catchment slope is 5°, cca 80% of the locality is in the category of 7° slope, and strongly sloped land exceeding 7°covers 20% of the catchment area.

2. Material and Methods

To estimate the nitrogen and phosphorus burden of surface water due to the soil erosion, soil samples were collected from the surface layer (0–10 cm) in the entire studied catchment of the Jihlava river. The samples were taken as mixed – each from 20 points within selected representative areas of arable land. The samples were analysed for the total phosphorus and nitrogen content. The mean values of P_{tot} = 1.64 g.kg^{-1} (standard deviation (SD) was 1.59 g.kg^{-1}) and N_{tot} = 1.63 g.kg^{-1} (SD 0.37 g.kg^{-1}) corresponded to the results of basic monitoring and agrochemical soil testing that were provided by the Czech Central Institute for Supervising and Testing in Agriculture for the purposes of this study. Values of standard deviations are relatively high because samples of soil represented large area with different conditions and so differences in contain of P and N were significant.

The above-mentioned natural and manmade characteristics of the locality show that the nonpoint sources of potential agricultural pollution of surface water in the catchment can be divided into three groups:

- areas of agricultural land in alluvial locations situated in the immediate proximity of the banks of surface water courses and bodies,
- arable land threatened by soil erosion,
- localities with soils at risk of accelerated infiltration and nutrient leaching, including arable land connected to tile drainage systems.

Intensive agricultural management of riparian zones close to water bodies may lead to direct contamination of surface waters by soil particles (mechanically or by surface runoff), by applying fertilizers or pesticides close to the water course, or by grazing in riparian zones or spring areas, particularly during the periods of saturated soil profile. These risk areas were delimited in the study by analysing the distance of borders of arable land blocks and pastures (according to Land Parcel Identification System; LPIS – available in http://eagri.cz/public/app/lpisext/lpis/verejny/) from the banks of water bodies. The effects of inappropriate transformation of riparian zones to arable land were not quantified separately, but these zones were included into the calculation of the soil loss by water erosion.

Establishment of erosion risk for arable land

Soil erosion by water in the conditions of the Czech Republic represents a significant, relatively frequent source of contamination for water bodies. Particularly intensive transport of soil particles by surface runoff is observed in long sloping blocks of arable land with low resistance to erosion effects (Uhlířová, Kaplická & Kvítek 2009). The erosion risk in the catchment was determined in individual arable land blocks using the updated universal equation USLE (Janeček et al. 2012), with erosive effective rainfall factor R = 40 MJ.ha^{-1}.cm.h^{-1}. The analysis was performed in the GIS environment based on the digital terrain model (grid 5x5 m) and vector layers of arable land block borders (according to LPIS) and with the characteristics of soil cover defined by evaluated soil ecological units. The calculations of mean long-term soil loss by erosion were performed for 122 subcatchments. The volume of soil lost by erosion that could be potentially transported to the water course was then established using the sediment delivery ratio according to Robinson (1977): SDR = 34.853 * P - 0.2142 (%), where P is the catchment area in km^2. The phosphorus and nitrogen burden of surface water due to the soil erosion was estimated based on the knowledge of the sediment volume and the content of these elements in the soil according to the analyses and data of the Czech Central Institute for Supervising and Testing in Agriculture, with consideration of the ‘enrichment ratio’ (Janeček et al. 2012). The efficiency of erosion control measures was assessed by comparing the current long-term soil loss with its potential reduction induced by application of these measures.

Establishment of infiltration vulnerable localities

The soils vulnerable to accelerated infiltration were identified based on the evaluated soil ecological units, classified by Janglová, Kvítek and Novák (2003) into five relative infiltration categories. The layer of accelerated infiltration vulnerable localities was processed in GIS using the Synthetic Map of Groundwater Vulnerability (Kvítek et al., 2009) and merged with the map layer of established agricultural drainage systems adapted from the database of the former Agricultural Water Management Office. Accelerated infiltration depletes the soil profile particularly of nitrogen, which is then transported into subsurface water and subsequently into groundwater or surface water (Fučík et al. 2015, Doležal, Vacek & Zavadil 2005). Leaching of nitrogen and its theoretical changes induced by application of the designed measures were therefore calculated for the nitrate form, which for the purposes of the quantitative model were then converted to the concentrations and losses of total nitrogen. The effectiveness of annual intercrops in capturing the soil nitrogen was derived from the report of Haberle & Káš (2012), according to whom $N\text{-}NO_3$ leaching from arable land with catch crops is decreased by an average of 32% compared to the soils without intercrops (in comparable soil conditions). By excluding the wide-row crops, these losses are lower by an average of 42% (Fučík et al., 2012).

The nitrogen inputs from agricultural land were derived from the total balance of point and nonpoint source contributions (Ryšavý et al. 2013) in the 122 subcatchments. The total losses after the designed protective measures were calculated as a weighted mean of losses from areas with and without application of these measures. The effect of grassing on the changes in nitrogen leaching was calculated based on water quality monitoring in chosen subcatchments in the Jihlava river basin (Ryšavý et al. 2013).

Design of measures

By merging the raster layers representing individual partial risks of sheet agricultural pollution in the catchment (table 1) in GIS and using the scoring multi-criteria analysis (Rosen et al. 2013) we identified areas at high risk of nitrogen and phosphorus leaching into the surface water from agricultural land on the total area of 64 km^2 (5.5% of the total catchment area). These localities were then targeted by variants of proposed measures for conservation of the soil and water quality. List of types of measures applied for each variant is presented in table 2, an example of the designed measures in a part of the study locality is presented in Fig. 4.

Tab 1. Balance of risks of nonpoint agricultural pollution.

Origin of risk (evaluating criterion)	**Risk**	**Criterion value**	**Percentage of basin area (%)**
Soil erosion (G v t^{-1}.ha.year^{-1})	Non-significant	0 – 4	32.2
	Low	4 – 8	10.3
	Moderate	8 – 12	3.9
	High	12 – 24	2.8
	Very high	> 24	0.6
Infiltration (rate)	High	High	18.2
	Very high	Very high	1.7
Drainage (area in km^2)	High for permeable soil	81.1	7.0
Proximity to borders of agricultural land blocks and water body banks (distance in m) Note: Agricultural land area is included as area of whole relevant blocks.	Non-significant	> 100	11.0
	Low	50.1 – 100	5.5
	Moderate	25.1 – 50	1.1
	High	5.1 – 25	2.1
	Very high	≤ 5	5.8

G = average long term soil loss

Tab 2. Summary of variants of measures for reducing nonpoint agricultural pollution.

Variant	Measures for reducing the effects of soil erosion by water	Measures for reducing risk of compound leaching	Measures area (km^2)
1a	Exclusion of wide-row crops from selected* land blocks (EWRC)	Exclusion of wide-row crops from selected* land blocks	144.8
1b	Protective agro-technologies (seeding to mulch or stubble) in blocks selected for variant 1a	Cultivation of catch crops in selected blocks (same as in var. 1a)	144.8
2a	Organizational and technical erosion control measures (grassing, interceptive ditches)	Grassing of infiltration vulnerable areas	38.1
2b	Organizational and technical erosion control measures (grassing, interceptive ditches)	Cultivation of catch crops in infiltration vulnerable areas	38.1
3	Organizational and technical measures (including grassing of infiltration vulnerable areas and riparian zones) in combination with EWRC	Synergistic action of erosion control measures according to var. 3 and grassing of infiltration vulnerable areas	167.1
4	Erosion control grassing in selected land blocks (same as in var. 1a), grassing of infiltration vulnerable areas and riparian zones	Erosion control grassing in selected land blocks (same as in var. 1a), grassing of infiltration vulnerable areas and riparian zones	167.1

* = identified by risk analysis

Fig 3. Harmfull effects of soil erosion event in 2012 near Dalešice.

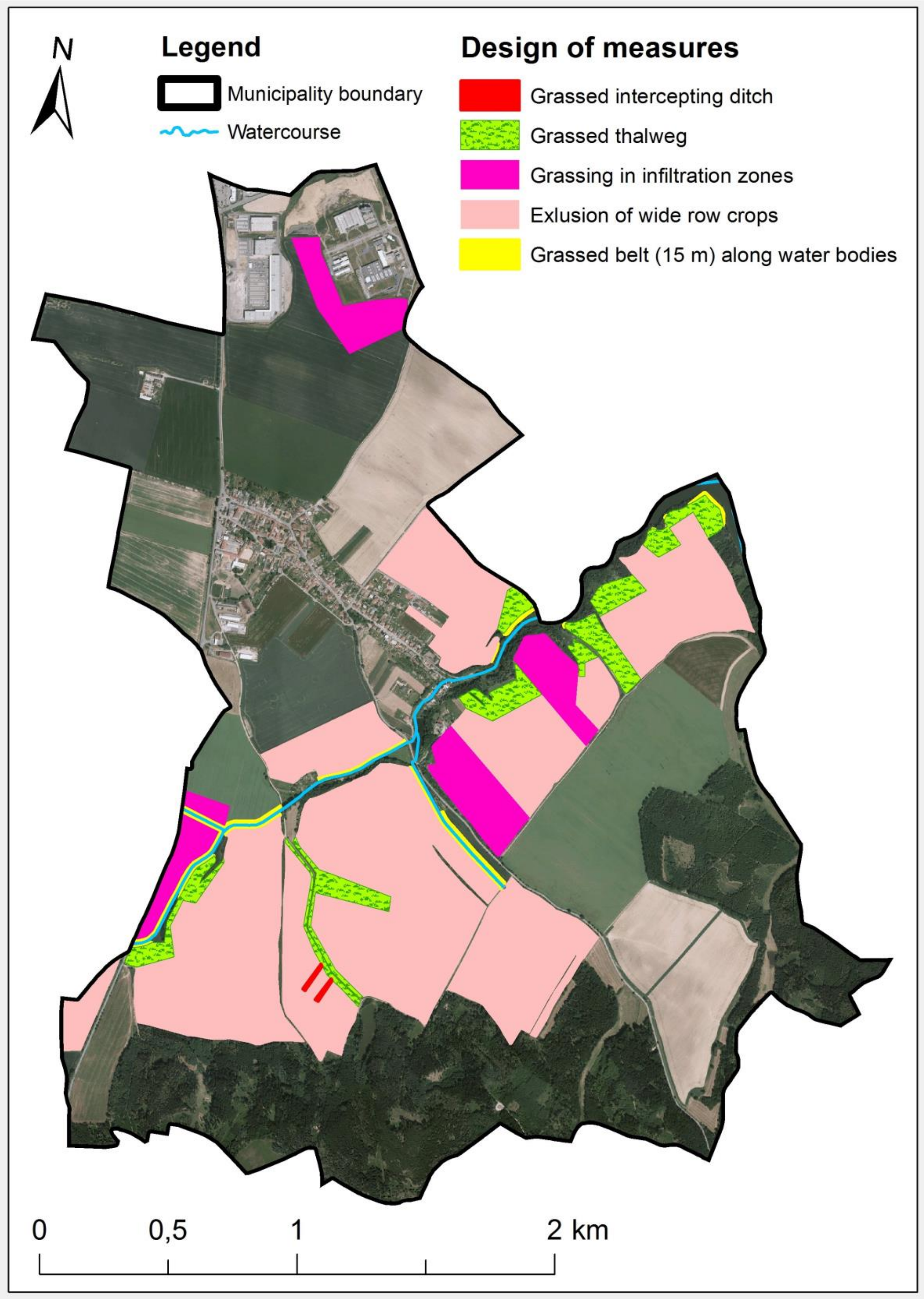


Fig 4. Detail of a part of the study catchment (municipality Střítež) with designed measures according to variant 3.

3. Results and Discussion

For current state of the Jihlava river basin it was found out that average long term input of suspended load evoked by soil erosion is 48930 t.year^{-1}. It means potential input of P_{tot} = 168.6 t.year^{-1} and N_{tot} = 79.8 t.year^{-1} as a result of erosion processes. N_{tot} leaching through soil profile to water bodies reaches 1015 t.year^{-1} in the basin in its current state. The model calculation of the effectiveness of the proposed measures summarized in 122 subcatchments is given in table

3. The effectiveness of erosion control measures is expressed as a percentage of reduction of erosion load transport, and the reduction of nitrogen and phosphorus input compared to the present state corresponds to this proportion in table 4. This table also contents potential effectiveness of the measures in decreasing of N leaching. Duchemin & Hogue (2009) have noted that in the first year after their introduction, the effectiveness of biotechnical measures is lower than that calculated using a model.

Tab 3. Potential transport of N and P after hypothetical implementation of designed measures.

Variant	Transport of suspended load ($t.year^{-1}$)	P_{tot} transport ($t.year^{-1}$)	N_{tot} transport ($t.year^{-1}$)	N_{tot} leaching ($t.year^{-1}$)
1a	39290.8	135.4	64.1	914.5
1b	31462	108.4	51.3	937.9
2a	46141	159	75.3	893.2
2b	46141	159	75.3	1001.8
3	35963.6	124	58.7	783.6
4	25052.2	86.3	40.9	319.7

Tab 4. Potential effectiveness of the measures for reducing nonpoint agricultural pollution.

Variant	Transport of suspended load – present ($t.year^{-1}$)	Decrease in transport of suspended load (%)	N_{tot} leaching – present ($t.year^{-1}$)	Decrease in N_{tot} leaching (%)
1a	48930 (100%)	19.7	1015 (100%)	9.9
1b		35.7		7.6
2a		5.7		12.0
2b		5.7		1.3
3		26.5		22.8
4		48.8		68.5

Variant 3 features balanced effect of designed measures both in restricting soil erosion and N leaching. Application of measures according to this variant might potentially reduce the effects of soil erosion by water on surface water quality by 26.5% and at the same time decrease the level of total nitrogen washing out by 22.8%. The highest effects were observed with variant 4, which however presumes grassing of all the identified areas at risk and therefore becomes unmanageable in practice

As expected (Janeček et al., 2012), soil erosion causes higher contamination of water by phosphorus than by nitrogen. The 'erosion phosphorus' is mainly transported in insoluble form and bound to the sediment particles, and for this reason usually without triggering the eutrophication process. Reynolds & Davies (2001) have confirmed that phosphorus from arable land is not bioavailable in water, but the hazardous water load may be caused by surface runoff from over-fertilized land blocks. Of course, Nuno-Goncalo & Penny (2012) and others have reported that the phosphorus load from agricultural land in surface water is significantly lower than from point (municipal) pollution sources in the catchment.

Despite the specific characteristics of erosion processes and their mostly local effects on the surface water quality, their impact should not be underestimated. Soil erosion by water results in selective loss of fine soil particles that play a key role in the soil fertility, its characteristics, and binding of nutrients. Intensive or repeated rainfall-runoff events may lead to the loss of the entire surface humus horizon (Uhlířová, Kaplická & Kvítek 2009). Therefore soil erosion by water results in degradation of physical, chemical and biological soil properties (Janeček et al. 2012). In the conditions of Bohemian-Moravian Highlands, the erosion loss increases the soil skeletal nature, decreases its retention potential and deteriorates its sorption abilities. The soil is poor in organic matter because agricultural companies often prefer industrial fertilizers than farm manure, and the seeding procedures frequently disregard the agronomic rules for maintenance of the soil fertility. Overall, erosion in damaged soil increases the need for supplying nutrients while accelerates the infiltration rate, potentially creating conditions for further growth of surface water contamination by nitrogen leaching from the soil profile (Ryšavý et al. 2013).

Research focused on nitrogen leaching from arable land attempts to find potential ways to reduce fertilization, use intercrops or winter crops, and promote changes in agro-technology, or use combination of these techniques while maintaining the crop yields. In general, nitrogen leaching from the soil displays significant inter-annual variability, namely due to the weather course (precipitation, temperature, soil moisture), content of accumulated nitrogen in the soil and intensity of its mineralization (e.g. Kaspar et al. 2012). In their long-term model evaluation of different variants of seeding procedures and fertilization, Laurent & Ruelland (2011) observed that light soils seeded with corn were most vulnerable to nitrogen. Utilization of catch crops (particularly oats) applied to 16% catchment surface resulted in ca 11–15% nitrates reduction in the water. The results shown in table 3 and 4 correlate well with these findings.

4. Conclusion

This project investigated the potential ways to reduce nonpoint agricultural pollution with focus on decreasing the effects of soil erosion by water and reducing the nitrogen leaching from infiltration vulnerable areas, particularly those connected to agricultural drainage. Both these aspects are well balanced in variant 3 of the proposed measures. This variant includes grassing of areas at risk of erosion, technical erosion control measures (interceptive ditches), grassing of infiltration vulnerable areas and exclusion of wide-row crops in other surfaces of blocks of arable land at high risk of erosion.

Measures adopted in the landscape that should reduce input of pollutants from nonpoint sources into the water environment must be proposed and applied as a complex multidisciplinary concept, i.e., related to their effectiveness, polyfunctionality, feasibility (both factual and legal) and the overall economic assessment, including environmental impacts. The measures designed by our study represent a complex of partial measures reducing various risk factors in the catchment of the water reservoir. Farmers in the Czech Republic usually manage land with maximum exploitation of the state support for particular commodities, but often without respecting the hydrologic parameters of the locality or the proximity or condition of water bodies. Water resources and their quality are therefore very vulnerable from the viewpoint of agricultural management and application of various compounds including fertilizers. Despite all so far exerted legal efforts we must state that neither the present agricultural policy nor the water management policy pay due respect to the present needs of soil and water protection under the conditions prevailing in Czech Republic. Moreover, the targeted preference for selected commodities results in spreading their plantation, thus representing an extreme burden for surface water due to the application of hazardous compounds, namely plant protectives and various nutrients. It is therefore imperative to exploit the present tools of agricultural policy to their full extent, require observance of the conditions for soil and water conservation, and develop and innovate the means and rules for permanent sustainability of rural development with respect to nature and landscape preservation.

Some space for application of the proposed measures in the Jihlava river basin has been opened by land consolidations (Kadlec et al. 2014), due to the fact that projects of common facilities include erosion control, water management aspects, and requirements for environmental protection in the relevant cadastral areas. With the goal of potential utilization of land consolidations as an implementing tool, the results of this study were provided to the Vysočina District and to the State Land Office.

Acknowledgment

The manuscript was prepared with support of project No. 444/2400/2012-2013 of the Research Institute for Soil and Water Conservation and of the Ministry of Agriculture of the Czech Republic within the framework of research concept No. MZE0002704902 and project QJ1620040. The manuscript contains also some research results obtained thanks to funding from the Norwegian Financial Mechanism 2009–2014 under Project Contract No. 7F14341 "Assessing water quality improvement options concerning nutrient and pharmaceutical contaminants in rural watersheds". The authors thank to Renata Duffková for advices regarding nitrogen leaching and to Šárka Takáčová for the help with the English.

References

[1] Bauwe, A., Tiemeyer, B., Kahle, P. & Lennartz, B. (2015). Classifying hydrological events to quantify their impact on nitrate leaching across three spatial scales. *Journal of Hydrology,* 531, 589–601. Doi: 10.1016/j.jhydrol.2015.10.069.

[2] Doležal, F., Vacek, J. & Zavadil, J. (2005). *Problems of potato growing and irrigation in highland regions of Czechia with regard to water resources protection*. In: Integrated Land and Water Resources Management: Towards Sustainable Rural Development. 21st European Regional Conference ICID, Frankfurt (Oder) and Słubice, 15.–19. 5. 2005. [Proceedings on CD].

[3] Duchemin, M. & Hogue, R. (2009). Reduction in agricultural nonpoint source pollution in the first year following establishment of an integrated grass/tree filter strip system in southern Quebec (Canada). *Agriculture, Ecosystems & Environment*, 131(1–2), 85–97. Doi: 10.1016/j.agee.2008.10.005.

[4] Fučík, P., Zajíček, A., Duffková, R. & Kvítek, T. (2015). Water Quality of Agricultural Drainage Systems in the Czech Republic – Options for Its Improvement. In Lee T. S., ed., *Research and Practices in Water Quality*. Rijeka: InTech Publishing. DOI: 10.5772/58512.

[5] Fučík, P., Novák, P. & Žížala, D. (2014). A combined statistical approach for evaluation of the effects of land use, agricultural and urban activities on stream water chemistry in small tile-drained catchments of south Bohemia, Czech Republic. *Environmental Earth Science* 72(6), 2195–2216. Doi: 10.1007/s12665-014-3131-y.

[6] Fučík, P., Kaplická, M., Kvítek, T. & Peterková, J. (2012). Dynamics of Stream Water Quality during Snowmelt and Rainfall – Runoff Events in a Small Agricultural Catchment. *CLEAN – Soil, Air, Water*, 40(2), 154–163. Doi: 10.1002/clen.201100248.

[7] Gilbert, N. (2015). Europe sounds alarm over freshwater pollution. *Nature*, 02 March 2015. Doi: 10.1038/nature.2015.17021.

[8] Haberle, J. & Káš, M. (2012). Simulation of nitrogen leaching and nitrate concentration in a long-term field experiment. *Journal of Central European Agriculture*, 13(3), 416–425. Doi: 10.5513/jcea.v13i3.1533.

[9] Janeček, M. et al. (2012). *Ochrana zemědělské půdy před erozí. Metodika.* Praha: Powerprint.

[10] Janglová, R., Kvítek, T. & Novák, P. (2003). Kategorizace infiltrační kapacity půd na základě geoinformatického zpracování dat půdních průzkumů (pp. 61–81). In: Lhotský, J. & Královcová, K., eds., *Soil and Water 2/2003*. Praha: Research Institute for Soil and Water Conservation.

[11] Kadlec, V., Žížala, D., Novotný, I., Heřmanovská, D., Kapička, J., Tippl, M. (2014). Land consolidations as an effective instrument in soil conservation. *Ekológia* 33(2), 188–200. Doi: 10.2478/eko-2014-0019.

[12] Kaspar, T. C. et al. (2012). Effectiveness of oat and rye cover crops in reducing nitrate losses in drainage water. *Agricultural Water Management*, 110, 25–33. Doi: 10.1016/j.agwat.2012.03.010.

[13] Köhler, K., Duynisveld, W. H. M. & Böttcher, J. (2006). Nitrogen fertilization and nitrate leaching into groundwater on arable sandy soils. *Journal of Plant Nutrition and Soil Science*, 169(2), 185–195. Doi: 10.1002/jpln.200521765.

[14] Kvítek, T., Novák, P., Michlíček, E., Slavík, J. & Fillipi, R. (2009). *Syntetická mapa zranitelnosti podzenbiích vod*. Praha: Research Institute for Soil and Water Conservation, v.v.i., Geotest Brno, a.s.

[15] Laurent, F. & Ruelland, D. (2011). Assessing impacts of alternative land use and agricultural practices on nitrate pollution at the catchment scale. *Journal of Hydrology*, 409(1–2), 440–450. Doi: 10.1016/j.jhydrol.2011.08.041.

[16] Li, S., Zhang, L., Du, Y., Liu, H., Zhuang, Y. & Liu, S. (2016). Evaluating phosphorus loss for watershed management: integrating and weighting scheme of watershed heterogeneity into export coefficient model. *Environmental Modeling & Assessment*, 21(5), 657–678. Doi: 10.1007/s10666-016-9499-1.

[17] Novotny, V. & Chesters, G. (1989). Delivery of sediment pollutants from nonpoint sources: a water quality perspective. *Journal of Soil and Water Conservation*, 44(6), 568–576.

[18] Nuno-Goncalo, M. & Penny, J. J. (2012). Catchment phosphorus losses: An export coefficient modelling approach with scenario analysis for water management. *Water Resources Management*, 26(5), 1041–1064. Doi: 10.1007/s11269-011-9946-3.

[19] Panagos, P. et al. (2015). The new assessment of soil by water erosion in Europe. *Environmental Science & Policy*, 54, 438–447. Doi: 10.1016/j.envsci.2015.08.012.

[20] Reynolds, C. S. & Davies, P. S. (2001). Sources and bioavailability of phosphorus fractions in freshwaters: a British perspective. *Biological Reviews*, 76(1), 27–64.

[21] Robinson, A. R. (1977). Relationship between soil erosion and sediment delivery (pp. 159–167). In *Erosion and Solid Matter Transport in Inland Waters Symposium*. IAHS – AISH Publication, 122.

[22] Rosen, L., Volchko, Y., Söderqvist, T., Back, P.-E., Norin, M., Brinkhoff, P., Bergknut, M. & Döberl, G. (2013). SCORE: Multi-criteria analysis (MCA) for sustainability appraisal of remedial alternatives. In *Bioremediation and Sustainable Environmental Technologies – 2013*. Second International Symposium on Bioremediation and Sustainable Environmental Technologies, Jacksonville, FL; June 10–13, 2013.

[23] Ryšavý, S. et al. (2013). Jakostní model povodí Jihlavy nad VD Dalešice. Brno: Pöyry Environment.

[24] Sharpley, A. N. (1985). The selection erosion of plant nutrients in runoff. *Soil Science Society of America Journa*l, 49(6), 1527–1534. Doi: 10.2136/sssaj1985.03615995004900060039x.

[25] Sova, V. & Tippl, M. (1999). Vliv ochranného obdělávání půdy na obsah fosforu v sedimentu srážkového odtoku. *Vodní hospodářství* 2, 21–24.

[26] Tesfahunegn, G. B. & Vlek, P. L. G. (2014). Assessing sediment enrichment ratio in Mai-Negus catchment, Northern Ethiopia. *Soil & Water Research* 9(1), 38–45.

[27] Trnka, M., Brázdil, R., Dubrovský, M., Semerádová, D., Štěpánek, P., Dobrovolný, P., Možný, M., Eitzimger, J., Málek, J., Fromayer, H., Balek, J. & Žalud, Z. (2011). A 200-year climate record in Central Europe: implications for agriculture. *Agronomy for Sustainable Development*, 31(4), 634–641. Doi: 10.1007/s13593-011-0038-9.

[28] Uhlířová, J., Kaplická, M. & Kvítek, T. (2009). Water erosion and characteristics of sediment load in the Kopaninský stream basin. *Soil and Water Research,* 4(1), 39–46.