Long-term Progress in Water Quality after Grassing and Fertilization Reduction in Spring Areas of the Šumava Mountains

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Abstract: The changes in water quality caused by grassing of arable land followed by the reduction in the use of fertilisers after 1989 are demonstrated on an example of two tile-drained subcatchments in spring areas in the Šumava Mountains. The original water quality monitoring was performed in the mid-1980s, at the time when the area was used as tile-drained arable land. The monitoring was renewed in 2004 under different, i.e. extensive, land use conditions. The principal reason for the new monitoring at the site was to see what sort of changes, if any, in water quality had occurred in the location, particularly in terms of nitrate nitrogen leaching. The concentrations and ranges of the values of all water quality indices monitored decreased after grassing. The average nitrate concentration of 39.5 mg/l (min. 9.2 mg/l, max. 104.8 mg/l) in 1983–1985 dropped to 17.5 mg/l (min. 3.5 mg/l, max. 33.3 mg/l) in 2005–2007. The greatest decrease (by 85%) was found in average ammonium concentrations. A positive effect of current agricultural management in foothill areas on the reduction of all water quality parameters monitored was confirmed.

Keywords: subcatchment; land use change; tile drainage; water quality

Hydrological situation in regions – and in small catchments in particular – is influenced by the management on agricultural and forest lands. The type of agricultural land use will significantly affect not only the runoff parameters, but also the quality of water.

After 1990, the countryside in the Czech Republic, and particularly in its so-called marginal areas, was greatly restructured. The extent of arable land was greatly reduced in favour of permanent grasslands, and the stocking rate per hectare dropped from 0.8–0.9 to 0.3 A.U. (Gergel 2006). The areas in foothill regions that had been previously tile-drained using systems with a rather intensive "field" type of drain spacing, were grassed.

The installation of tile draining systems is a common agricultural management practice to help improve the moisture and aeration conditions that shorten the water retention periods in biologically active unsaturated soil zones. This change in the moisture and air conditions in soil is manifested by greater organic matter mineralisation, and thus

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a greater risk of the non-point contamination of surface water and groundwater with nutrients and pesticides (Tomer *et al.* 2003; Doležal & Kvítek 2004; Behrendt *et al.* 2005; Tiemeyer *et al.* 2006).

The balance and transformation of nutrients in catchments is significantly affected by the location and the size of the characteristic landscape components (agricultural land, forest, human settlements, agricultural structures, water management structures, etc.). The types of land management and specific crop growing and livestock rearing technologies will, to a large extent, influence the course of transformation and transport processes of elements in the soil and the environment, not to mention other anthropogenic activities that directly or indirectly alter the biochemical cycles of elements (Šimek 2003).

One of the most closely monitored water quality indices in catchments are surface water nitrate concentrations (see, e.g. Nitrate Directive 676/91EEC). The total amount of nitrates leached by surface water is determined by the relationship between the agricultural activities and basic catchment characteristics including its hydrological processes (Vagstad *et al.* 2004). Leaching of nitrates to groundwater and their runoff to surface water depends on nitrogen excess, hydrological regime, land use, soil type, and climatic conditions of the year (Shepherd *et al.* 2001; Oenema *et al.* 2005).

Important factors influencing the incidence of nitrates in surface water are land consolidation, single crop farming, and the type of agricultural land draining (Kvítek 1994; Hartog & Griffioen 2003). A comparison between nitrate concentrations and different land uses revealed the relationship between the land use and mean nitrogen concentrations in the stream. Nitrate concentrations increase depending on the type of land use in the catchment, from forests, meadows, and pastures to arable land (Pekárová & Pekár 1996; Kvítek 2001; Ruiz *et al.* 2002; Worall *et al.* 2003; Kvítek *et al.* 2005). The effect of ploughing on nitrate concentrations has been described by, e.g., Stoate *et al.* (2001).

Another important water characteristic is its phosphorus concentration, which determines eutrophication process in the aquatic environment (Duvigneaud 1988). The issue of phosphorus in water is closely connected with the issue of fertilisation of agricultural land and with erosion (Kelly & Whitton 1998).

MATERIAL AND METHODS

Study area

The Jenínský stream catchment is in the B_{10} climatic region (moderately warm, very wet region; moderately warm, very wet upland district),

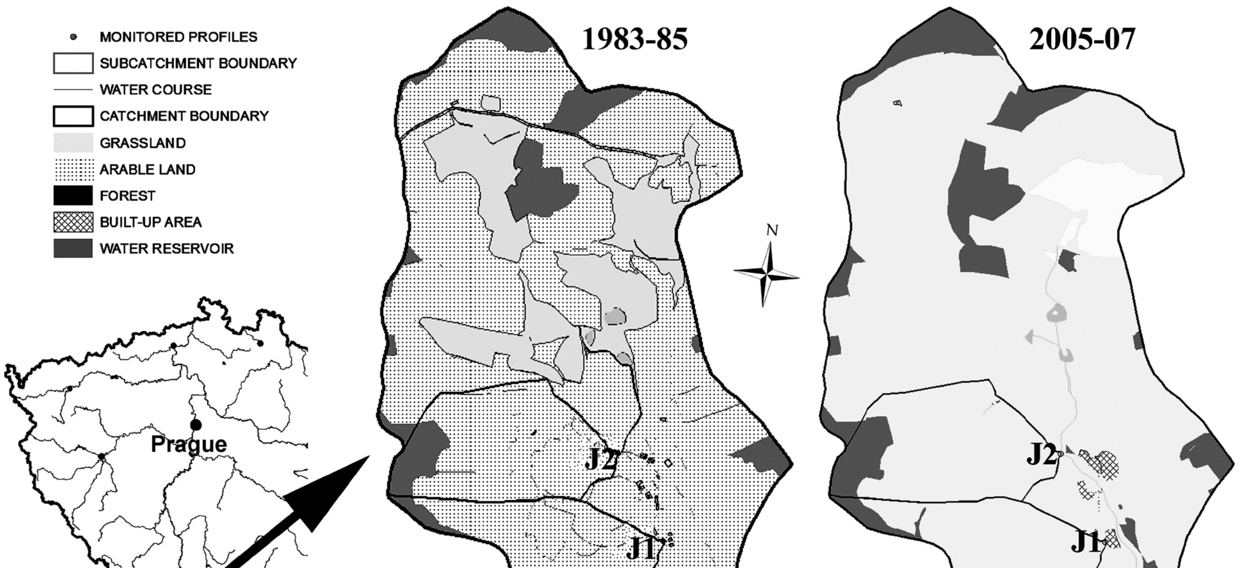

Figure 1. The situation map of the study area with detailed locations of subcatchments

its average altitude above sea level being 650 m, average annual total precipitation 715 mm, and average annual temperature 6.7°C. The total size of the Jenínský stream catchment is 4.64 km^2.

The Jenínský stream catchment is situated in the former Český Krumlov administrative district. Two subcatchments J1 and J2 were monitored in the Jenínský stream catchment (see Figure 1). These two subcatchments are located westerly of the town of Jenín in the Rybník cadastre area at 655 to 820 m above sea level.

The predominant soil types are cambisols. The bedrock is mica schists passing to mica gneisses, the weathering of which produced soils with a high mica content.

In 1978–1979, the land was tile-drained. The waterlogging of the area was the result of high precipitation rates, water seepage in mid-slopes and high ground water table, which produced slope water with both confined and unconfined groundwater levels at lower altitudes. Another reason for the unbalanced water regime was the stagnant surface water in depressions.

The catchment was intensively farmed in the 1980s. After 1989, the land use patterns in foothill, less fertile areas in the Czech Republic, underwent major changes, and the catchment is now used for extensive farming (90% pastures). The common features of extensive farming in Jenínský stream catchment are the majority of pastures and the absence of fertilising.

Description of sampling profiles

The sampling profile J1 is a pipe outlet for a section of the drainage system that drains pastures to the Jenínský stream. The subcatchment area of this sampling profile is 47 ha.

The sampling profile J2 is a pipe outlet for a section of the drainage system that drains pastures to the Jenínský stream. The subcatchment area of this sampling profile is 55 ha.

For the data processing purposes, water quality analysis data from the period of 1983–2007 were used. From the monitoring data collected in the 1980s, the data from the 3-year-long period

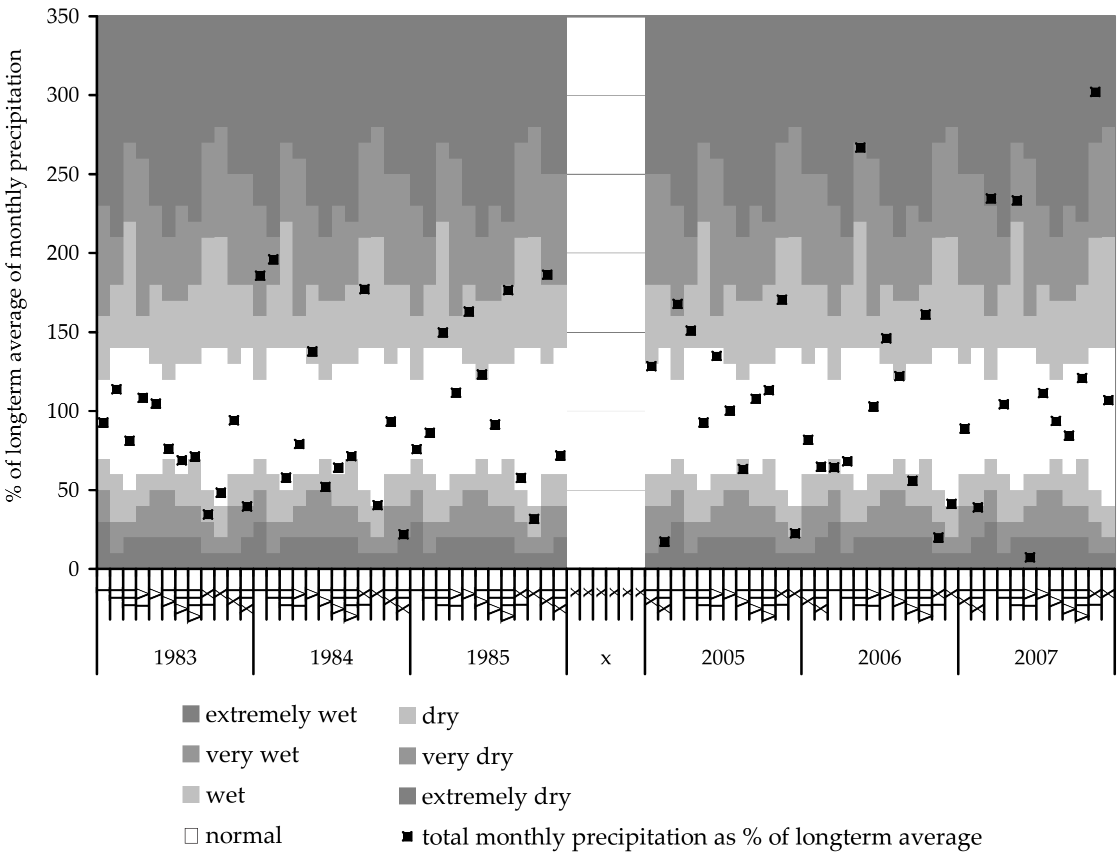

Figure 2. Monthly precipitation totals in the Jenínský stream catchment in the two study periods expressed as percentages of long-term averages of monthly total precipitation

Table 1. Percentage changes in average concentrations and ranges of water quality parameters monitored in the two study periods (100% = values in 1983–1985)

Water quality parameters	Average value (mg/l)		Change (%)	Range (mg/l)		Change (%)
	1983–1985	2005–2007		1983–1985	2005–2007	
J1						
NO_3^-	37.75	22.10	–41	77.00	29.80	–61
NH_4^+	0.25	0.05	–80	5.37	0.15	–97
PO_4^{3-}	0.13	0.13	0	0.76	0.29	–62
Ca^{2+}	21.82	17.61	–19	43.13	7.50	–83
Mg^{2+}	7.09	4.21	–41	17.79	2.30	–87
K^+	3.70	2.71	–27	15.20	5.20	–66
COD_{Mn}	3.12	1.96	–37	13.15	12.75	–3
J2						
NO_3^-	41.10	12.80	–69	94.50	20.70	–78
NH_4^+	0.46	0.05	–89	5.84	0.29	–95
PO_4^{3-}	0.22	0.18	–18	3.64	0.25	–93
Ca^{2+}	23.13	18.20	–21	53.97	7.60	–86
Mg^{2+}	7.31	4.43	–39	20.72	3.20	–85
K^+	7.05	4.98	–29	40.20	5.20	–87
COD_{Mn}	5.76	2.52	–56	54.29	12.75	–76

between 1 January 1983 and 31 December 1985 were used because only at that time unbroken data series were available. For this reason, it was not possible to assess the data in individual hydrologic years separately. For the assessment of the current situation (1 October 2004–31 October 2007) three hydrologic years long periods were used. Two three-year periods (i.e. 1983–1985 and 2005–2007) were compared.

The samples for the chemical analysis were taken fortnightly. The chemical analysis indices monitored included chemical oxygen demand (COD_{Mn}), and nitrates, ammonium, phosphates, calcium, potassium, and magnesium contents.

RESULTS AND DISCUSSION

Precipitation

Because the entire hydrologic cycle is basically driven by precipitation, it has to be considered the main component (Brutsaert 2005). It directly influences the runoff and, consequently, water quality. Figure 2 shows total monthly precipitation expressed as percentages of long-term averages, and the totals are compared with the limits of intervals for the evaluation of normality of individual months valid for the territory of the Czech Republic (Kožnarová & Klabzuba 2002). The comparison between annual precipitation totals in 1983–1985 and 2005–2007 and long-term average annual precipitation totals gave the following results in individual years: 1983 – very dry, 1984 – normal, 1985 – wet, 2005 – normal, 2006 – normal, 2007 – wet.

Water quality

All water quality parameters monitored at the two profiles responded to grassing and reduction in the use of fertilisers with a drop in concentrations and markedly narrower ranges of the values measured (Table 1). This was the most noticeable in the parameters related to nitrogen, i.e. nitrates and ammonium. Similar results have been found by Kolář *et al.* (2002). With a majority of parameters, they reported a drop in concentrations of the compounds monitored (drop of nitrate N to 54.66% of the original level, ammonium to 21.73%, calcium to 75.77%, magnesium to 81.52%, and potassium to 57.97%).

The 1983–1985 values were to a large extent affected by the practiced application of fertilisers to arable land. The amonium nitrate fertiliser LAV (27% of nitrogen) and compound fertiliser NPK (12% of nitrogen) were used. The amount differed

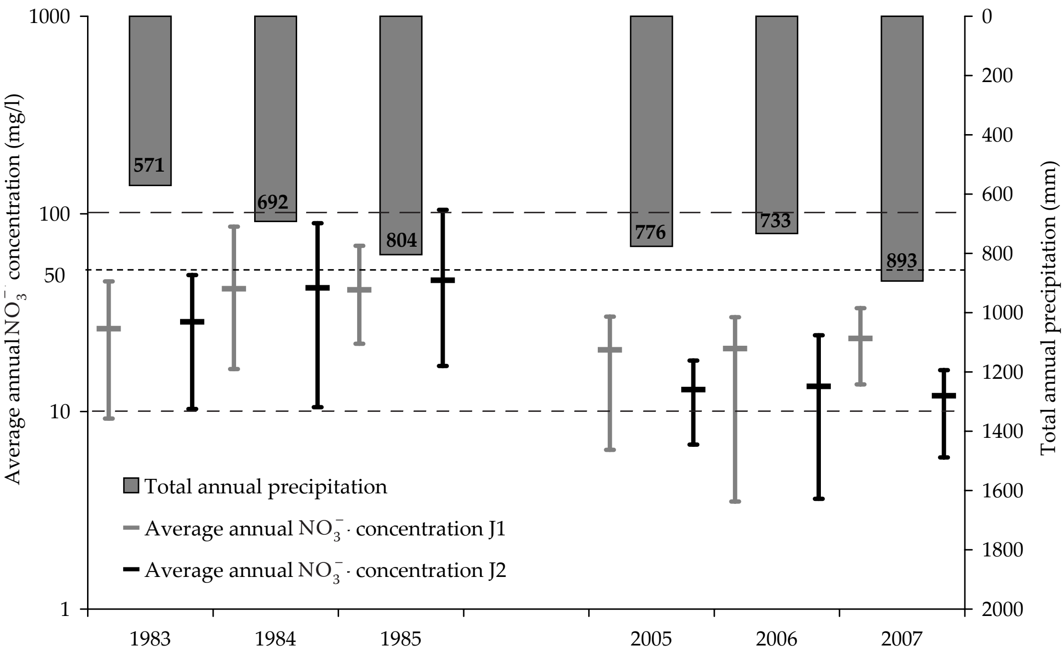

Figure 3. Graphical representation of average annual nitrate concentrations (error bars indicate the maximum and minimum values) and total annual precipitation in the two study periods in subcatchments J1 and J2

each year according to the crop plants grown and fertilising plan of each farming entity. Mineral nitrogen use in the Český Krumlov administrative district had decreased continuously since 1980s (134 kg N/ha), and by 2000/2001 (31 kg/ha of N) had declined to 23% of the 1984/1985 level (source: Czech Statistical Office). The land use changed from arable land to grassland in 1992. Since then, no fertlisers (neither mineral nor organic) have been applied. The only nitrogen input is from grazing and deposition. Deposition contributes to the nitrogen input to the environment in this area approximately by 26 kg/ha/year constantly since 1980s (Gergel 2006).

The overall change in the agricultural management (use of fertilisers, conversion of arable land to grass ecosystems, grazing) was reflected at the most in ammonium concentrations. Ammonium concentrations are basically functions of complicated ion-exchange reactions in the soil environment and of immediate uptake by plants. In the 1980s, ammonium concentrations were significantly influenced by the use of water-soluble fertilisers, mainly liquid manure, as obvious from the data from the first of the periods monitored. After the change, the values were low and stable, without variations.

Average phosphate ion concentrations at profile J1 remained nowadays the same as they were in the 1980s (the only parameter monitored to remain the same) and decreased slightly at sampling profile J2. This situation is probably due to a very strong bond between phosphate ion and the soil environment, and the contamination of pastures by grazing livestock. This included poorly movable phosphates bound with calcium, magnesium, iron, etc.

Calcium concentrations in the first study period were probably affected by ameliorative liming applied after the drainage system was built. The differences between individual years are ascribable to the effects of the crop grown at the time, with lower concentrations linked with winter cereals and increasing concentrations following the growing of maize and spring cereals. Calcium thus responds more promptly to soil aeration and the periods with no vegetation cover. The decrease in calcium concentrations is less marked than in other water quality parameters monitored (except phosphates).

Current average magnesium concentrations decreased equally by 40% as compared with the 1983–1985 concentrations at both profiles. The measured values and their ranges correspond to surface water concentrations found in the Czech Republic (Gergel 2006), and they also correspond to the magnesium-to-calcium ratios in surface water published by Pitter (1999). The variability of concentrations in the first period is ascribed

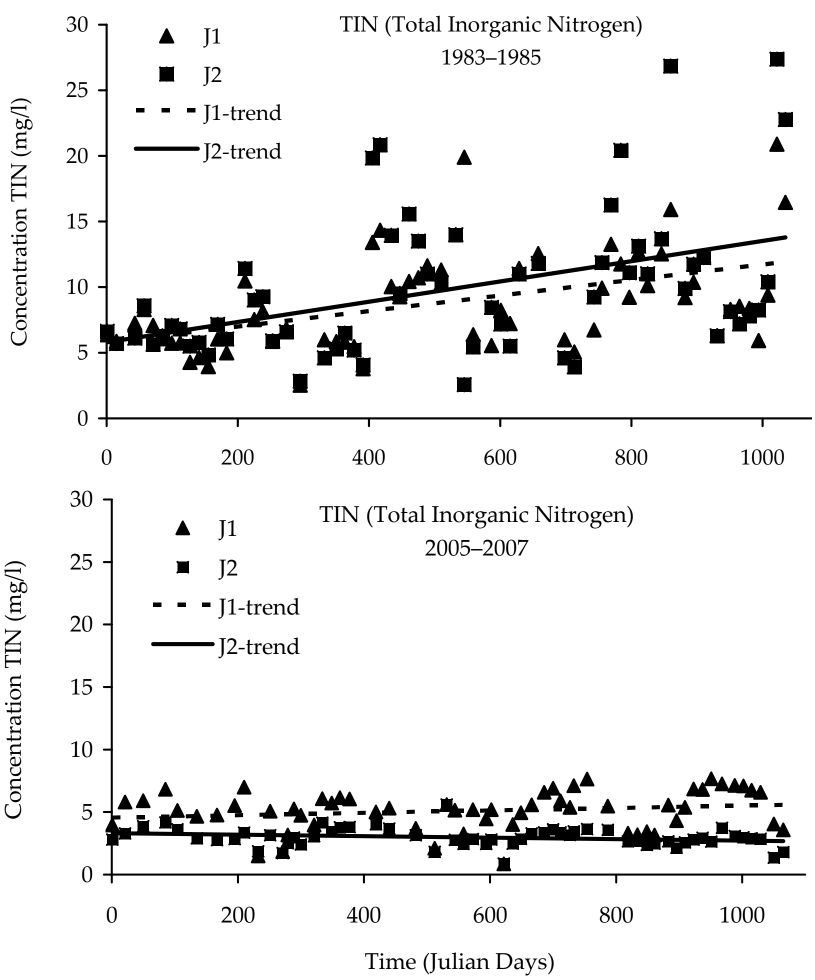

Figure 4. Linear trends of TIN concentrations in the two study periods

to the type of farming in the area, specifically to maize, and the use of classical ploughing and liquid manure. Nowadays, the values are decreased and the variations are less marked.

Potassium in water is mainly present as cation K^+ because of its poor complementation (Šimek 2003). Soil potassium concentrations at the time when the land was used as arable land were affected by its use as fertiliser. Potassium concentrations in subcatchments and their variations do not cause any major surface water pollution problems.

The COD_{Mn} results depend very much on the fertilisation system used. The wide range of values in this case is again ascribed to the liquid manure system of organic fertilisation used at the time. Extremely high values at profile J2 in 1983–1985 were found immediately after the application of liquid fertilisers that rapidly seeped to the drainage system. This is also suggested by high concentrations of ammonium and phosphorus measured in the same period. The supply of organic matter after grassing was minimised, no liquid fertilisers are nowadays used in the area and the values are more balanced.

The data in Figures 3 and 4 (and also Table 2) show that average nitrate concentrations in 2005–2007 were in the range of minimum values from 1983 to 1985. This fact conforms to the finding that nitrate leaching from under permanent grasslands is demonstrably lower than from under arable land (Njos 1994).

The maximum nitrate concentration of 104.8 mg/l was recorded in June 1985 at the profile J2, and the second highest concentration of 104.6 mg/l at the same profile in December 1985.

It follows from Figure 4 that the total inorganic nitrogen (TIN) concentrations differ greatly in accordance with the types of farming in the areas studied. There are great differences between the situation in the 1980s and the situation at the beginning of this century. In 1983 to 1985, statistically significant rising linear trends can be discerned in TIN concentrations in catchments J1 and J2 ($P < 0.05$), while in the 2005–2007 period

Table 2. Basic statistical characteristics of nitrate concentrations (in mg/l)

Evaluated characteristics	1983–1985		2005–2007	
	J1	J2	J1	J2
Number of samples	62	62	58	58
Minimum	9.2	10.3	3.5	3.6
Median	35.3	35.9	22.8	12.4
Average	37.7	41.1	22.1	12.8
0.9-quantile	57.9	68.8	30.4	16.4
Maximum	86.2	104.8	33.3	24.3

the linear trend levelled off (shows no significant trend towards an increase or decrease). A similar trend of continuously growing TIN (nitrates) concentrations in the 1980s were also mentioned by some other authors (e.g. Duigon *et al.* 2000; Jarvis 2000; Owens & Bonta 2004; Rotz *et al.* 2005) claiming that the higher nitrate concentrations were mainly due to the intensive type of farming with high amounts of fertilisers used.

The differences between TIN concentrations at sampling profiles J1 and J2 in 1983-85 were not very significant because the same land management systems were used in both subcatchments (the same crop and the same agrotechnological processes). The 2005–2007 period exhibited greater variability and higher absolute TIN concentrations at profile J1, which could be due to a non-uniform intensity of livestock grazing at the subcatchments studied. Higher TIN concentrations at the profile with more frequent livestock grazing were also confirmed by Heathwaite *et al.* (1990), who suggested that nitrogen consumed by the cattle on the pastures grazed is returned to the soil in urine or faeces, which are a highly effective sources of nitrogen contamination of water.

CONCLUSIONS

All water quality parameters monitored at the two profiles followed responded to grassing and fertilisation reduction by a drop in concentrations and markedly narrower ranges of the values measured.

There is a considerable improvement (decrease) of NO_3^- concentrations in the Jenínský stream catchment with relation to the limit of the EU Nitrates Directive 91/676/EEC. A very significant decrease occurred in average ammonium and nitrate concentrations (by 80–89% and 41–69%, respectively).

The only monitored water quality parameter which remained almost the same was phosphate ion.

The extensive farming management described is wide-spread in such foothill areas in the Czech Republic nowadays and for its positive effect became one of the key points of water quality protection.

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