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Long-Term Improvement in Surface Water Quality after Land Consolidation in a Drinking Water Reservoir Catchment

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Abstract

Dumbrovský M., Sobotková V., Šarapatka B., Váchalová R., Pavelková Chmelová R., Váchal J. (2015): Long-term improvement in surface water quality after land consolidation in a drinking water reservoir catchment. Soil & Water Res., 10: 49–55.

The aim was to explore how soil and water conservation measures, applied in the process of land consolidation, affected nutrient concentrations in surface waters of the Hubenov drinking water reservoir in the Českomoravská vrchovina Upland. A significant part of the catchment serves as a protection zone for the reservoir. The protection measures, such as restrictions on the maximum amount of manure and N and P fertilizers, were applied in the case study area according to recommendations of a land consolidation project. The Hubenov reservoir water resources were monitored for twenty years (1990–2010) in order to collect water quality data on nitrate nitrogen ($N\text{-}NO_3^-$), total phosphorus (P_{tot}), and total suspended solids. The results of monitoring indicate a linear trend of decrease in $N\text{-}NO_3^-$ and P_{tot} concentrations following the soil and water conservation measures applied.

Keywords: land use; protection zone; soil and water conservation; water pollution

Hydrology and water quality, especially in small rural catchments, are influenced by the way in which agricultural and forested areas are managed. High losses of nutrients from mineral and organic fertilizers, mostly from arable land, negatively affect the quality of many surface waters. The source areas of intensive diffuse pollution must therefore be identified and made less harmful, especially in the catchments that supply water to drinking water reservoirs. The conservation measures, based on the Good Agricultural and Environmental Conditions, have to be applied. Namely, the extent of arable land should be reduced in favour of permanent grassland. This pertains in particular to tile-drained lands, because they represent an enhanced risk of nonpoint pollution of surface waters and groundwater with nutrients and pesticides (Doležal & Kvítek 2004; Lexa *et al.* 2006; Tiemeyer *et al.* 2006; Fučík *et al.* 2008).

The land consolidation measures of the indicated type (conversion of arable land into grassland, field banks, field roads, protective grass infiltration/buffer strips, broad base terraces, grassed water flow paths, erosion-prone wide-row crops, etc.) were implemented in the Hubenov reservoir catchment in the Českomoravská vrchovina Upland. They caused reduction in sediment delivery and improvement of water quality (Konečná *et al.* 2011). Similar links between land management activities and stream water quality in a dyke-irrigated pastoral catchment were reported by Monaghan *et al.* (2009).

The total amount of nutrients (mainly nitrates and phosphorus) leached into surface waters and

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groundwater is determined by agricultural activities and basic catchment characteristics, including its climatic and hydrological conditions, land use, and soil types (Kelly & Whitton 1998; Vagstad *et al.* 2004; Oenema *et al.* 2005).

The aim of the present study was to explore the relationship between soil and water conservation measures applied in the process of land consolidation and the subsequent changes in nutrient concentrations in surface waters of the Hubenov drinking water reservoir.

MATERIAL AND METHODS

Case study area and management. Two subcatchments (S1 and S2) of the Hubenov drinking water reservoir catchment were monitored. The catchment is located in the Českomoravská vrchovina Upland in the Jihlava administrative district (Figure 1), about 100 km south-east of Prague (Hrbáček & Albertová 2011). The sampling profile S1 is an outlet of the Maršovský stream with a subcatchment area of 16.17 km^2, while S2 is an outlet of the Jedlovský stream with a subcatchment area of 18.33 km^2.

The Hubenov drinking water reservoir catchment (34.5 km^2) lies in a moderately warm climatic region of moderate to medium wetness, in a hilly to submountainous area with average rate of surface runoff, high groundwater runoff, and relatively stable total runoff. The soils are permeable, the groundwater circulation is shallow, and the hydrographic network is relatively well developed (Dumbrovský *et al.* 1996). At its normal operational level, the water surface in the reservoir lies at 522 m a.s.l. and covers an area of 51.6 ha (Hrbáček & Albertová 2011). The average altitude of the catchment is 640 m a.s.l., the average annual precipitation total is 680 mm, and the average annual air temperature is 6.8°C. The dominant soil type is Dystric Cambisol with sandy loam or loamy sand topsoil.

Many areas in the catchment are drained by a systematic tile drainage, which converts a part of surface runoff into subsurface runoff. The tile-drainage systems are located in the floodplain areas in the valleys of watercourses but partly also in the adjacent recharge or transport zones (Table 1).

The agricultural inputs of nitrogen and phosphorus in organic and mineral fertilizers were calculated using the data from three agricultural companies that farm the relevant areas in the Hubenov reservoir catchment (Table 2).

The land consolidation was carried out between the years 1995–2000 on approximately 85% of the land within the Hubenov reservoir catchment in accordance with the design made by Dumbrovský *et al.* (1996). After the land consolidation, the previous water resource protection zones were revised in accordance with valid regulations as follows:

Protection of Maršovský stream catchment (S1). The land use in the first protection zone is exclusively grassland and has a total area of 159.82 ha. The second protection zone includes grass vegetation and arable land and has a total area of 247.29 ha, out of which the proposed proportion of arable land is Z_2^x = 75.88%. The third protection zone includes all other agricultural lands in the catchment and has a total area of 362.71 ha, out of which the proposed proportion of arable land is Z_3^x = 89.00%.

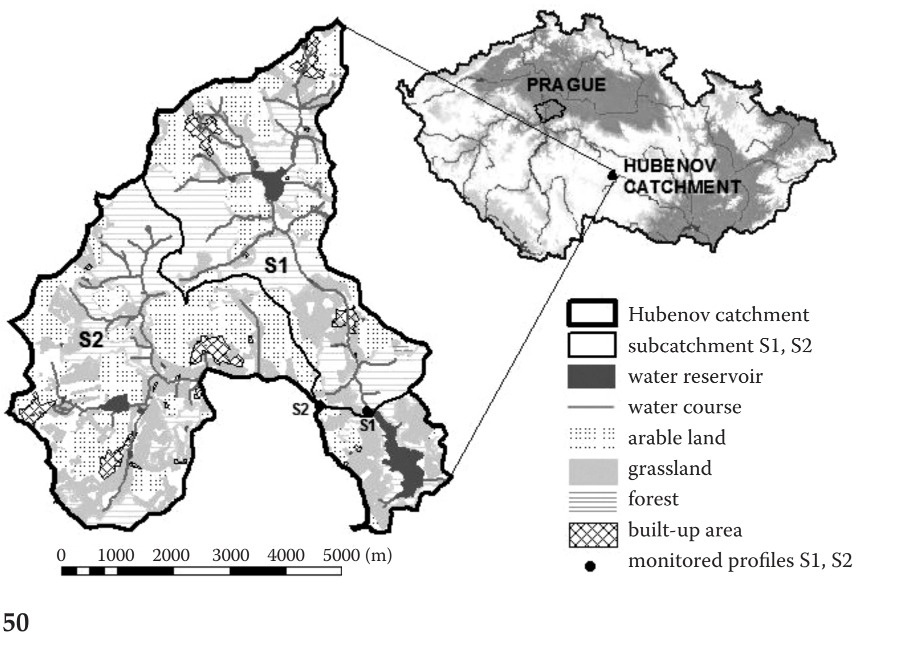

Figure 1. Situation map of the study area with its subcatchments

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Table 1. Tile-drained areas in the Hubenov reservoir catchment

Area	Catchment (km^2)	Mean specific runoff ($1/s/km^2$)	Mean total runoff (1/s)
Tile drainage	3.42	7.52	25.72
Affected by tile drainage	7.68	7.14	54.84

Protection of Jedlovský stream catchment (S2). The land use in the first protection zone is exclusively grassland, its total area being 244.16 ha. The second protection zone is partially grassed; its total area is 250.81 ha and the proposed proportion of arable land is Z_2^x = 12.83%. The third protection zone includes all other agricultural lands in the catchment. Its total area is 441.86 ha and the proposed proportion of arable land is Z_3^x = 47.17%.

The proposals for the allowed proportion of arable land were based on the maximum permissible nitrate content in the soil and recommended cropping practices according to Neuberg (1990). The maximum allowed nitrogen input into waters was calculated according to Šimunek (1993). The details are elaborated in the report by Dumbrovský *et al.* (1996). In addition to the conversion of arable land into grassland, the land consolidation also implied the creation of field banks and field roads and protective grass infiltration/buffer strips. More than 11.6 ha of broad base terraces, 40 ha of protective grass infiltration strips, and 9.1 ha of grassed flow paths were created, together with supporting linear vegetation. The actual areas of arable land converted to grassland were 122 ha in S1 and 766 ha in S2. The grassed water flow paths covered 2.6 ha in S1 and 6.5 ha in S2. The broad-base terraces covered 3.62 ha in S1 and 7.94 ha in S2. The protective grass infiltration strips covered 12.9 ha in S1 and 27.1 ha in S2. The erosion-prone wide-row crops, which had previously been grown on almost 350 ha, were eliminated.

The hydrological and erosion control measures included conversion of all tile-drained areas in groundwater accumulation zones into grassland, consolidation of existing erosion control ditches, application of agronomic measures (limiting the amount of fertilizers and using the best management practices), insertion of runoff delaying barriers into tile-drainage manholes, and building small water reservoirs in places of concentrated runoff.

Technical assistance and subsidies paid since 1995 had a positive effect on the agricultural land management in the catchment. The willingness of land users to apply soil conservation measures increased. Catch crops started to be used on a larger scale and the methods of cultivation became more environment-friendly.

Statistical methods. Statistical methods were used to demonstrate quantitatively how nutrient levels in surface waters responded to the reduced use of mineral fertilizers associated with the changes in land use and to the implementation of erosion control measures best management practices. The data were processed using *t*-tests, U-tests, and univariate analysis of variance (ANOVA) with STATISTICA (Version 12) and SPSS Statistics (Version 20) software. Simple linear regressions were used to demonstrate the temporal trends of nutrient concentrations.

RESULTS AND DISCUSSION

Figure 2 shows the average annual nitrate nitrogen concentration in the outlets of subcatchments S1 and S2 in the periods 1990–1999 (before and during the land consolidation) and 2000–2010 (after the land consolidation). The concentration trend corresponds to that reported by Žlábek *et al.* (2008) for arable lands and grassland of the Šumava Mts.

Table 2. Total N and total P input from organic and mineral fertilizers applied to agricultural land in the Hubenov reservoir catchment within 1994–2010 (in kg/ha/year)

Date	N_{tot}	P_{tot}	Date	N_{tot}	P_{tot}	Date	N_{tot}	P_{tot}
1994	108.0	18.0	2000	100.0	12.5	2006	118.0	16.0
1995	90.0	21.1	2001	115.0	13.0	2007	109.0	12.0
1996	106.3	15.5	2002	114.0	14.5	2008	112.0	10.0
1997	90.2	10.1	2003	104.0	14.0	2009	107.0	11.0
1998	116.0	10.9	2004	112.0	13.0	2010	104.0	11.0
1999	108.0	11.1	2005	124.0	17.0	–	–	–

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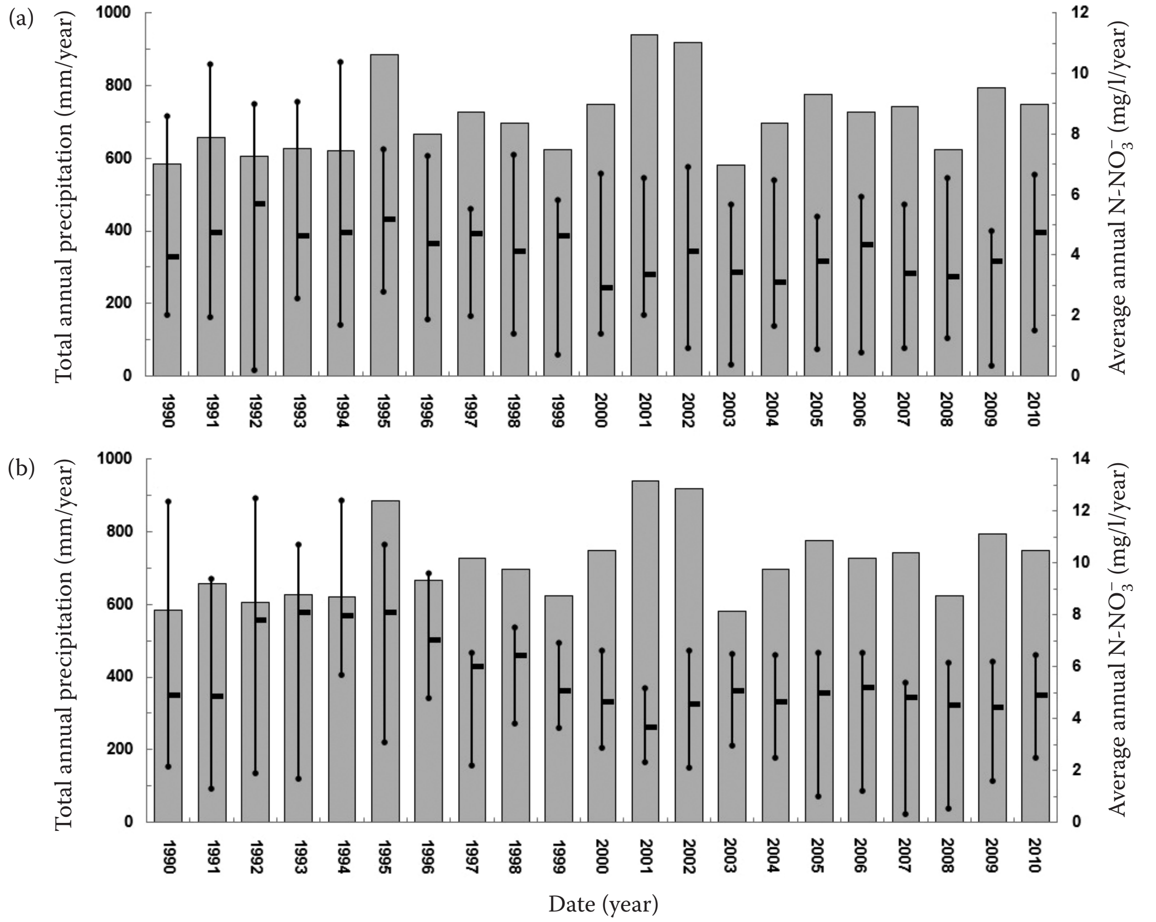

Figure 2. Annual N-NO_3^- concentrations (vertical lines indicate the maximum, minimum, and average (cross bar) values) and annual precipitation totals (shaded bars) in 1990–2010 in subcatchments S1 (a) and S2 (b)

In the Hubenov catchment it was not only N-NO_3^- but also total P and suspended solids in the outlet points of the two subcatchments (S1 and S2) that showed a decreasing linear trend in 1990–2010 (Figures 3–5, Tables 3 and 4). This trend is statistically significant (Table 3). After 2000, as soon as the land consolidation started to be fully effective, the water quality parameters more or less stabilized on new reduced levels. The overall change in the agricultural management of the area was primarily reflected in

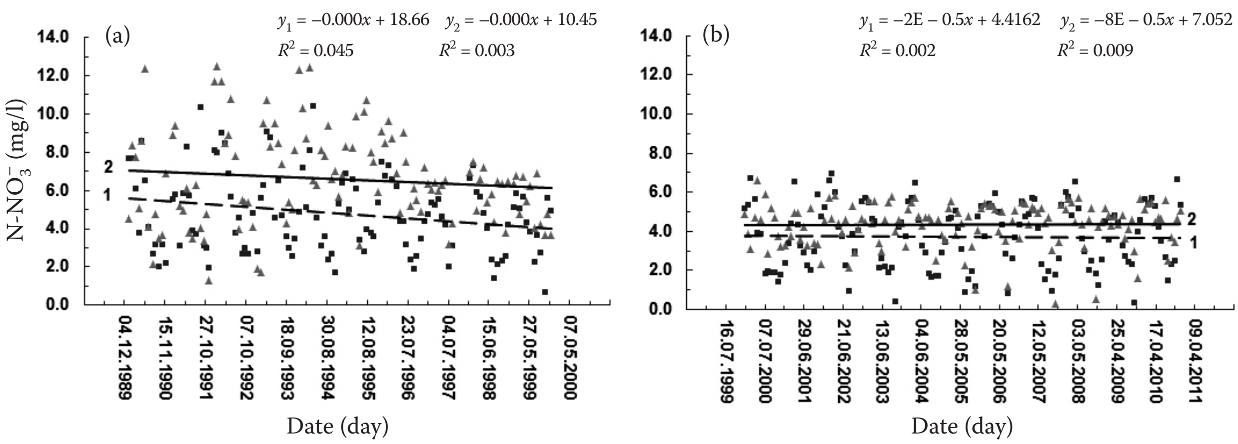

Figure 3. Linear regressions of N-NO_3^- concentration vs time in the profiles S1 (dashed line) and S2 (solid line) for the study periods 1990–1999 (a) and 2000–2010 (b)

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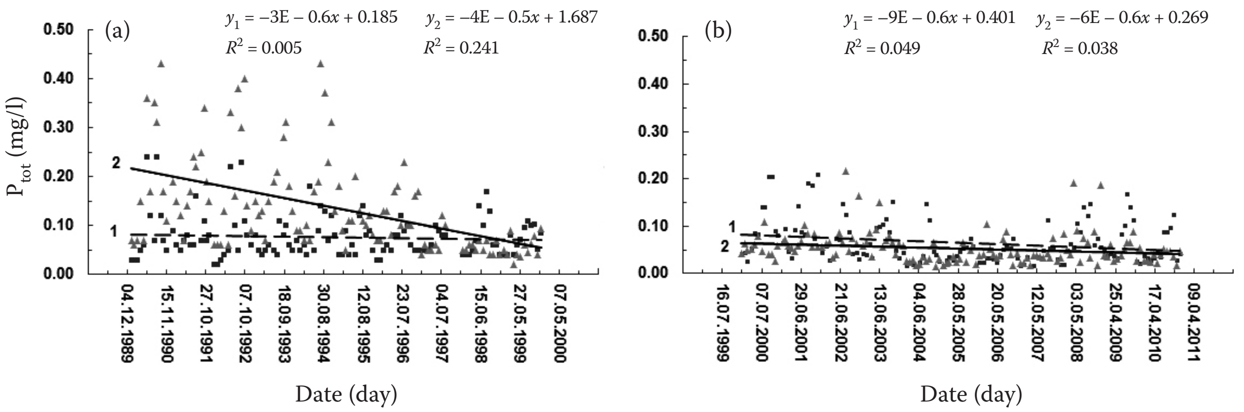

Figure 4. Linear regressions of P_{tot} concentration vs time in the profiles S1 (dashed line) and S2 (solid line) for the study periods 1990–1999 (a) and 2000–2010 (b)

the nitrate concentration trend. The average $N\text{-}NO_3^-$ concentrations in profiles S1 and S2 were 4.76 and 6.45 mg/l, respectively, for the period 1990–1999, having dropped to 3.73 and 4.34 mg/l, respectively, for 2000–2010 (Table 3). This conforms to the finding that the nitrate leaching from permanent grasslands is demonstrably lower than that from arable land (Njos 1994). The average P_{tot} concentrations in S1 and S2 were 0.08 and 0.14 mg/l, respectively, for 1990–1999, having dropped to 0.07 and 0.05 mg/l, respectively, for 2000–2010 (Table 3). A similar statistically conclusive reduction was also found in terms of suspended solids in the profile S2, but was not confirmed in S1.

The *t*-tests confirmed ($\alpha = 0.05$) that the mean nutrient concentrations at S1 and S2 after the implementation of erosion control measures were lower than before (Table 3). This result is supported by U-tests, which, as non-parametric tests, are more robust. Similar results also follow from the univariate analysis of variance, in which the input of nutrients was also taken into consideration. The average amount of nitrogen applied per ha was slightly larger after 2000 (110.8 kg/ha) then in the period 1994–1999 (103.1 kg/ha) (Table 2), but this fact was not reflected in increased concentrations of $N\text{-}NO_3$ in the streams or in the Hubenov reservoir. The phosphorus input was very low in both decades (on average, 14.5 and 13.1 kg/ha per year respectively; Table 2) and there was no evidence of excessive phosphorus load in the reservoir, because the phosphorus was firmly bound to the soil. In general, the results indicate an improvement in water quality after the implementation of the erosion control measures.

If these results are compared with published data, we can see that Žlábek *et al.* (2008) found similar trends in small agricultural catchments in the Šumava Mts. Krause *et al.* (2008) described similar results in catchments of Estonia following a reduction in application of fertilizers, an increase in the area of permanent grassland, and implementation of better farm management practices. Several other studies (Worral & Burt 1999; Ferrier *et al.* 2001; Lenhart *et al.* 2003; Matějíček *et al.* 2003; Buck *et al.*

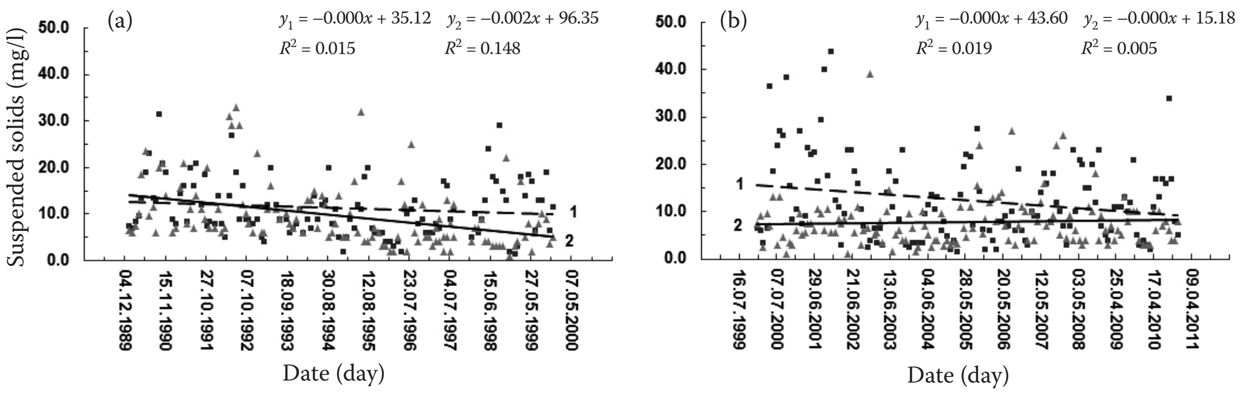

Figure 5. Linear regressions of the concentration of suspended solids vs time in the profiles S1 (dashed line) and S2 (solid line) for the study periods 1990–1999 (a) and 2000–2010 (b)

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Table 3. Average nutrient concentrations, contents of suspended solids (in mg/l, and results of groups comparison by means of *t*-tests, U-tests, and the univariate analysis of variance considering the input of nutrients to the agro-ecosystem over the periods 1990–1999 and 2000–2010 in the subcatchments S1 and S2

Parameters	1990–1999		2000–2010		*t*-test	U-test	ANOVA
	average value	SD	average value	SD			
S1							
$N\text{-}NO_3^-$	4.76	1.99	3.73	1.64	0.000	0.003	0.004
P_{tot}	0.08	0.04	0.07	0.05	0.053	0.404	0.358
Suspended solids	11.26	5.86	11.10	6.38	0.841		
S2							
$N\text{-}NO_3^-$	6.45	2.16	4.34	1.12	0.000	0.000	0.000
P_{tot}	0.14	0.10	0.05	0.03	0.000	0.048	0.022
Suspended solids	9.53	6.85	6.95	3.33	0.000		

SD – standard deviation

2004; Doležal & Kvítek 2004; Oenema *et al.* 2005; Poor & McDonnell 2007; Fučík *et al.* 2008) found the relationship between nutrient concentration in water and the land cover, especially the proportion of arable land, in the same range as in our research. All water quality parameters monitored in the two closing profiles (S1 and S2) responded positively to the increased grassland area and the reduced fertilizer use, experiencing a decline in concentrations and markedly narrower ranges of the values measured (Tables 3 and 4). Similar results were also found by Kolář *et al.* (2002).

Table 4. Comparison of average values of other water quality parameters (in mg/l) monitored in subcatchments S1 and S2 over the study periods 1990–1999 and 2000–2010 (100% = 1990–1999)

Water quality parameters	Average value		Change (%)
	1990–1999	2000–2010	
S1			
Dissolved oxygen	8.36	10.60	27
BOD_5	4.26	3.97	–7
COD_{Cr}	26.46	31.22	18
$N\text{-}NH_4$	0.35	0.14	–61
Chloride	16.27	11.35	–30
Sulfate	49.29	44.77	–9
S2			
Dissolved oxygen	8.35	10.07	21
BOD_5	4.08	3.56	–13
COD_{Cr}	27.24	31.63	16
$N\text{-}NH_4$	0.49	0.14	–72
Chloride	19.11	11.38	–40
Sulfate	52.85	43.15	–18

BOD_5 – biological oxygen demand; COD_{Cr} – chemical oxygen demand

CONCLUSION

All water quality parameters monitored in the two profiles, S1 and S2, responded to the increase of grassland area, the soil erosion control measures, and the reduction of fertilizer application rates by a drop in concentrations and markedly narrower ranges of measured values. Considerable improvement (decrease) in $N\text{-}NO_3^-$ concentration in the two profiles conforms to the limit stipulated by the EU Nitrates Directive (Council Directive 91/676/EEC:1991). There was also a reduction in the average P_{tot} concentration.

The protection and rational use of land in water resources protection zones by means of land consolidation offers a potential to establish flexible, environmentally friendly, and sustainable agriculture that considers environmental aspects and aesthetic demands and at the same time adopts scientifically-based crop production and soil management technologies. The catchment management described in the present study is becoming widespread in water protection zones of the Czech Republic and is now regarded as one of the key points in water quality protection, which means that a large part of the Czech landscape in the protection zones of drinking water reservoirs shall be restructured by comprehensive land consolidation projects.

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