The Impact of Artificial Drainage on Water Quality in Two Model Areas in the Bohemian Forest Foothills

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Abstract: This contribution arises from a broader research assignment dealing with the changes in soil properties and characteristics which have occurred following the artificial drainage of some agricultural soils in the Czech Republic. The current state is statistically compared with the state before the drainage. Thanks to the Research Institute for Soil and Water Conservation database, extensive sets of historical data are available. To enable a more detailed evaluation of the changes discovered, we chose two smaller study areas with different soil use. In the first area (Haklovy Dvory – arable land) there is intensive use of the soil, while in the other area (Železná – pastures) the use is not intensive. Historical data from about 30 years ago on the quality of surface and ground (well) water in the Železná area were taken as a starting point. The same types of water quality analyses were then made with water samples taken semi-annually in the Železná area since 2004 and once only (in 2005) in the Haklovy Dvory area. That led to the creation of an extensive body of information of water quality in the study areas. Within the framework of this information, the recent data, being still constantly supplemented, and the historical data on tile drainage, surface (stream) and underground (well) water quality are compared. In the course of the monitoring we focused on the following chemical indicators in the water: pH, alkalinity-acidity, total hardness, the concentrations of selected cations (magnesium, calcium, potassium, ammonia) and most important anions (bicarbonates, nitrates, nitrites, sulphates, phosphates, chlorides) and the electrical conductivity of the water. Individual samplings of surface and tile drainage water were, on the basis of the above mentioned analytical data, assigned appropriate quality categories according to the five-level pollution classification system defined by surface water quality standard (ČSN 75 7221). In Železná, no pronounced water pollution was found during the entire course of the monitoring, with the exception of one sampling point in the vicinity of which there was once a farmyard manure heap. By contrast, in the intensively managed Haklovy Dvory study area there was evidence of significant pollution of all tile drainage water samples. This finding supports our hypothesis about a direct impact of the type of agriculture practised in the area on the quality of tile drainage water. Both the use of fertilizers for agricultural crops and the intensive tillage of the soil have a commensurately large negative impact on the quality of tile drainage water and, subsequently, on the quality of water in surface watercourses.

Keywords: water quality; tile drainage; land use; soil

This contribution arises from a research assignment dealing with (mostly adverse) changes in soil chemical and physical characteristics which have occurred in agricultural soils as a result of their artificial drainage. These changes provide an example of the negative impact of intensive agriculture on the soil and the environment in general. The most pronounced changes caused by

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the intensification of agricultural production are those occurring both in the soil and, subsequently, in the surface and groundwater, and resulting from the extensive and often unjustified land drainage in past decades. Even though the existing drainage systems, which survive in our country from the Communist and pre-Communist eras, are, as a rule, no more regularly maintained and often function poorly, their negative impact on the quality of both soil and water may still persist.

Water quality is a relative notion that can be defined as the characteristic of water influencing its suitability for a specific use. It is usually defined in terms of physical, chemical and biological characteristics. Drainage water is in this respect no different from any other water sources and is also usable for some purposes within certain quality ranges. Beyond these limits, the drainage water must be disposed of in a manner that safeguards the usability or quality of the receiving water body for its presently established and potential uses (Madramootoo *et al.* 1997). The concentrations of salts, nutrients and other crop-related chemicals in drainage discharge vary with time and discharge rate. The nutrients occurring at highest concentrations are usually nitrogen (N) and phosphorus (P). The drainage effluent enriched with N and P stimulates eutrophication in receiving water bodies. Nitrogen can be present either in the organic or in the inorganic (mainly nitrate or ammonium) forms. Nitrate is the dominant form of N in subsurface drainage water. Nitrate-N, a soluble and non-sorbable N ion, has a great potential to move wherever water moves. Numerous studies document that the presence of a subsurface drainage system enhances the movement of nitrate-N to surface waters (e.g. Zucker & Brown 1998). High nitrate concentrations in subsurface drainage can originate from a number of sources: geological deposits, natural or added organic matter decomposition and deep percolation of nitrate from fertiliser applications. Nitrate contamination of subsurface drainage water has been documented, among other authors, by Madramootoo *et al.* (1992). Land use has a significant influence on the quality of drainage water. Fučík and Lexa (2006) documented that grass stands significantly reduce nitrate leaching whereas drainage water sampled under intensively farmed arable soils were more polluted.

The objective of our study was to compare the quality of drainage water in a non-intensively farmed area Železná (grasslands) and an intensively managed area Haklovy Dvory (arable lands). For Železná we have, in addition, a historical data set on the quality of surface and groundwater (Šmerda 1980), sampled about 30 years ago during the artificial drainage construction (Špaček 1974; Loskot 1976, 1979). The recent systematic monitoring of drainage water quality has been carried out in Železná since 2004. This offered us a possibility to compare how the water quality changed over time. A one-time only drainage water sampling was done in Haklovy Dvory in 2005.

MATERIALS AND METHODS

Soil and hydrological characteristics of the model areas

The Železná model area (Figure 1) is located in the Domažlice district on the border with Germany (49°34–35'N, 12°34-36'E). It lies at altitudes ranging up from 530 m above sea level. From a geological point of view, it belongs to the crystalline or moldanubic massif of the Bohemian Forest (Český Les), with a predominance of cordirietic gneiss and silmanitic-biotitic migmatised paragneiss with cordierite. The area falls within the moderately cool and wet climatic region of the Czech Republic (Mašát *et al.* 2002).

The largest part of its soil cover (approx. 40%) consists of Stagnic Cambisol (Dystric), while Haplic Stagnosols make up about a quarter of the soil cover, Haplic Gleysols almost one fifth, and Endogleyic Stagnosols one tenth. The remainder of the soil cover consists of Histic Gleysols, Cambisols (Dystric) and Gleyic Stagnosol (classified according to WRB 2006). The arterial drainage network comprises natural streams (the Nivní, Farský and Lesní) and artificial canals. The study area lies within the drainage basin of the Danube. In the 1980's the area was tile-drained systematically using flexible plastic pipes with the aim of improving the physical state of the soil, the water regime of the agricultural land, and improving and increasing agricultural production. A detailed hydropedological survey was carried out in the 1970's by the State Land Reclamation Authority (Špaček 1974) to provide a background for the drainage system design. The original design drawings are preserved. The systematic tile drainage system is composed of flexible plastic perforated pipes. Because of the susceptibility of the soil to

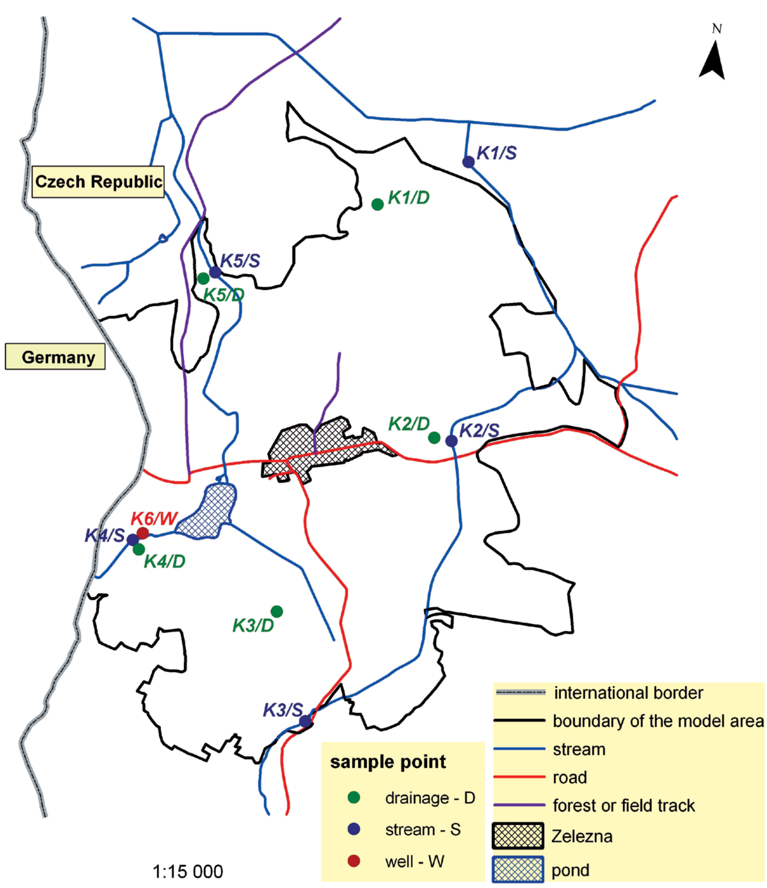

Figure 1. The Železná model area with its sampling points

silting, the pipes were wrapped around with glass-fibre fabric. The spacing of drains (L) depends varies, according to the degree of water-logging of particular spots, between 7.5 and 11 m. The depth of pipes placing was 1 m. The system is still functional. After the drainage system had been built, the drained areas were used for some time as arable lands, but today they are used as pastures. The present intensity of fertilising in the study area Železná is low, corresponding to the low farming intensity. Typically, carbamide is applied onto the pastures (trefoil-grasslands) in spring time. The soil is further regularly enriched by organic manure produced by free ranging animals. In the process of recent grassland reclamation after a period of no use, the areas were fertilised with potassium (50 kg/ha) and phosphorus (30 kg/ha).

The Haklovy Dvory study area (Figure 2) lies within the České Budějovice basin, north-west of České Budějovice town (48°59–60'N, 14°22–23'E). It is a flat area with little variation of the relief. It lies at altitudes ranging from 378 to 438 m above sea level. The area falls within the warm, moderately dry, basinal, continental climatic region of the Czech Republic. Its bedrock consists of sandy, clayey or mixed tertiary lacustrine deposits. A common characteristic of these deposits is a lack of plant nutrients and generally unfavourable chemical and physical characteristics. The soil cover consists most frequently of Haplic Stagnosols and to a lesser extent of Stagnic Combisols.

Due to the climate, the parent rock and the relief, an excessive amount of water is frequently held in the soil profile, which becomes in this way temporarily waterlogged and gleyised. For that reason, systematic tile drainage networks were built in the area during the 1980's. Their purpose was to improve the physical condition of the soils and to create more favourable conditions for intensive agricultural production. We did not have at our disposal the original drainage design documentation, but we found out some information about the systematic drainage systems from local farmers. The drains were made from baked-clay tiles. The average spacing of lateral drains was 20 m. Their depth of placing was 1.1 m below soil surface. The drainage systems in the area are still functional.

During the time of drainage water sampling (April and May 2005), winter oil rape *(Brassica napus napus)* was cultivated on almost all fields

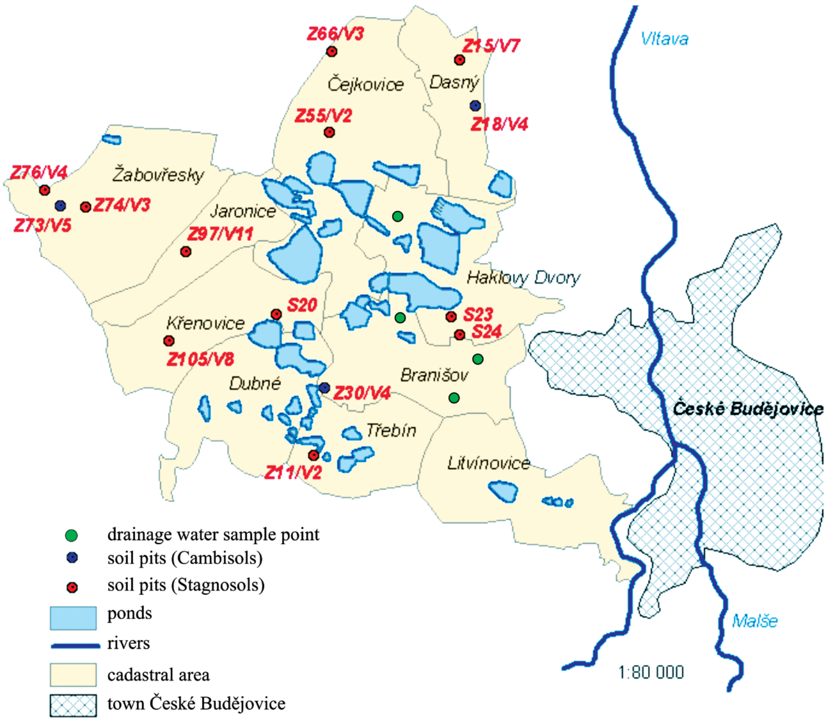

Figure 2. The Haklovy Dvory model area with its sampling points

of the model area Haklovy Dvory. The mineral fertilisers applied for the oil rape contained, on average, 90 kg/ha potassium, 22 kg/ha phosphorus and 100 kg/ha nitrogen. The nitrogen fertiliser was split into two applications, first in autumn before sowing and the other in spring by the spraying on the leaves. The agronomy was standard. In 2005, the average yield of oil rape seeds in the area was 3.62 t/ha.

Basic soil characteristics of both study areas are summarised in Table 1.

Table 1. Basic characteristics of main soil types in the study areas Železná and Haklovy Dvory

Study area	Soils according to WRB (2006)	Horizon	< 0.002	< 0.01	001–0.05	0.05–2	SOM (%)	pH (KCl)	CEC (mmol(+)/100 g)
			mm (%)						
Železná	Stagnic Cambisol (Dystric)	Ah	11.9	22.4	15.1	62.5	2.0	5.22	13.4
		Bwg	7.1	10.0	9.1	80.9	0.3	5.25	9.7
	Haplic Stagnosols	Ah	10.7	31.1	31.4	37.5	10.6	5.45	31
		Bg	17.2	24.2	21.0	54.8	0.3	5.26	11.2
Haklovy Dvory	Stagnic Cambisol (Dystric)	Ap	15.3	22.0	18.6	59.4	2.1	6.22	10.80
		Bwg	20.1	13.8	11.3	74.9	0.4	5.95	10.50

Study area	Soils according to WRB (2006)	Horizon	Sorption complex saturation (%)	Exchangeable ions (mmol(+)/100 g) Ca^{2+}	Mg^{2+}	K^{+}	Particle density (g/cm^3)	Bulk density (g/cm^3)	Porosity (%)
Železná	Stagnic Cambisol (Dystric)	Ah	81	7.52	0.82	0.29	1.47	2.66	46.4
		Bwg	69	6.91	0.83	0.22	1.54	2.72	43.4
	Haplic Stagnosols	Ah	73	20.0	6.46	0.37	1.00	2.37	59.4
		Bg	87	4.37	5.01	0.3	1.55	2.72	43.1
Haklovy Dvory	Stagnic Cambisol (Dystric)	Ap	77	8.26	0.99	0.46	1.52	2.76	42.90
		Bwg	76	6.82	1.45	0.40	1.69	2.71	38.91

Chemical characteristics of surface water quality

The quality of surface water is defined with respect to threshold values of selected chemical characteristics set out by the Czech standard ČSN 75 7221 (1998). According to the concentration of the most important cations (magnesium, calcium and ammonia), anions (sulphate, chloride, phosphate and nitrate) and the electrical conductivity EC of the water, the standard distinguishes five qualitative categories of quality. Unfortunately, the standard does not make specific reference to a number of other indicators which are, in their own way, also important and certainly significant from the point of view of health and hygiene. For example, the standard does not define the admissible ranges of pH values for differently polluted waters. It does not consider either the acidity and alkalinity or the total hardness of surface water, or the limiting concentrations of other important major ions (potassium, bicarbonate) or the concentration of nitrite, which is one of the most important indicators for the evaluation of the quality of drinking water.

For the purpose of evaluation of the changes in soil and water chemistry caused by drainage and by the subsequent use of the soil, we also monitored the changes occurring over time in the values of the above-listed indicators which the existing water quality standard does not consider, in order to have something to compare with the historical data from the Železná study area. Until the quality standard for surface water is revised, we cannot reasonably judge if the change in the values of these indicators would change the verbal quality classification of the stream or tile drainage water. There is considerable fluctuation in the values of those indicators both in space and time.

In Table 2 we also refer to the standards prescribing the methods of surface water analyses which were used for analysing our samples. As a matter of fact, the ammonium nitrogen was analysed spectrophotometrically using a Nessler reagent, the nitrate and nitrite nitrogen was analysed using an automated spectroscopic method, the chloride was analysed argentometrically, the sulphate gravimetrically (as $BaSO_4$), the phosphate spectrophotometrically with ammonium molybdate, the calcium volumetrically with chelaton III and the magnesium as a difference between the total hardness and the content of calcium cations.

The other chemical characteristics, which in this case play only a supplementary role, were determined according to the following standards: pH potentiometrically (ISO 10523 1996), the alkalinity, or ANC (acid neutralising capacity), by titration using phenolphthalein and methyl orange as indicators (ISO 9963-1 1996), the potassium using flame absorption spectrophotometry (ISO 9964-2 1996) and the nitrite spectrophotometrically (EN 26777 1995 or ISO 7150-2 1994).

Table 2. Thresholds of concentrations of ions and electrical conductivity (EC), defining the classification of surface water according to its quality (ČSN 75 7221 1998)

Chemical property	Quality class of surface water and its verbal classification					Analysed according to
	I. unpolluted	II. slightly polluted	III. polluted	IV. heavily polluted	V. very heavily polluted	
N-NH_3 (mg/l)	< 0.3	< 0.7	< 2.0	< 4.0	> 4.0	ISO 11732
N-NO_3 (mg/l)	< 3	< 6	< 10	< 13	> 13	EN 757453
P-PO_4^{3-} (mg/l)	< 0.05	< 0.15	< 0.4	< 1.0	> 1.0	EN 1189
Cl^- (mg/l)	< 100	< 200	< 300	< 450	> 450	ISO 6058
SO_4^{2-} (mg/l)	< 80	< 150	< 250	< 400	> 400	ISO 9280
Ca^{2+} (mg/l)	< 150	< 200	< 300	< 400	> 400	ISO 6058
Mg^{2+} (mg/l)	< 50	< 100	< 200	< 300	> 300	ISO 6059
EC (mS/m)	< 40	< 70	< 110	< 160	> 160	EN 27885

Overview of samplings

In the Železná model area we took water samples from six sampling points (K1 to K6). Eleven water samples were always taken at the same time, among which there were five pairs of samples from the stream and the adjacent tile drainage (K1 to K5) and a single sample of groundwater from a well at K6 (see Figure 1). The particular sampling points can be characterised as follows:

Sampling point K1

Stream water (*tributary of the Nivní stream*): clear water, colourless, no suspended sediment, water is capable of corroding cement by leaching and carbonates decomposition.

Tile drainage water: the first three samples were taken from functioning tile drainage with clean water, while later samples were turbid and smelling and, starting from the fifth sample, contained rusty suspended sediment. Starting from the sixth sample, there was an oil film on the surface and the water was almost stagnant.

Sampling point K2

Stream water (*Železný A stream*): clear, colourless water, leaching-, acid- and carbonate- corrosive to cement; since July 2007, the water had a light yellow colour.

Tile drainage water: originally slightly flowing, colourless clear water but, starting from the fourth sample turbid, it smelled and contained suspended sediment. In the field about 300 m upstream from the sampling point there was a disturbed heap of farmyard manure. Water in the manhole was almost stagnant.

Sampling point K3

Stream water (*Železný B stream*): clear, colourless water, leaching- and carbonate-corrosive to cement.

Tile drainage water: colourless, without any odour or suspended sediment. Starting from the fourth sample, it shows signs of a ferrous coating on adjacent surfaces; there is slightly coloured foam on water surface starting from spring 2007.

Sampling point K4

Stream water (*Farský A stream*): colourless, clear water without any odour or suspended sediment. Starting from the fourth sample, the stream water spills slightly over banks, causing the rise of water level in the tile drainage manhole. Stream water is leaching- and carbonate-corrosive to cement.

Table 3. Dates of water quality sampling in the Železná study area (for location of sampling points see Figure 1)

Date of sampling	Sampling point (see explanations below)										
	K1D	K1S	K2D	K2S	K3D	K3S	K4D	K4S	K5D	K5S	K6W
1974 (historical)	ø	x	ø	x	ø	x	ø	x	ø	x	x
11. 8. 2004	x	x	x	x	x	x	x	x	x	x	x
25. 11. 2004	x	x	x	x	x	x	x	x	x	x	x
27. 4. 2005	x	x	x	x	x	x	x	x	x	x	x
8. 9. 2005	x	x	x	x	x	x	x	x	x	x	x
16. 8. 2006	x	x	x	x	x	x	x	x	x	x	x
7. 11. 2006	x	x	x	x	x	x	x	x	x	x	x
17. 4. 2007	x	x	x	x	x	x	x	x	x	x	x
11. 7. 2007	x	x	x	x	x	x	x	x	x	x	x

D – drainage; S – nearest surface stream; W – well (groundwater); x – sampled; ø – not sampled

The historical samples, taken in 1974, were analysed for pH, acidity, alkalinity, total hardness and the concentration of ions of magnesium, potassium, bicarbonate and sulphate, for some of which no threshold values are stipulated by the surface water quality standard ČSN 75 7221 (1998)

Tile drainage water: Colourless, clear, and odourless. Starting from the fourth sample, there is ferrous coating on adjacent surfaces and, starting from the fifth sample, there are oil patches (perhaps diesel fuel) on the water surface; starting from spring 2007, suspended sediment and a light yellow coloration appear.

Sampling point K5

Stream water (*Farský B stream*): clear, colourless water, without any odour or suspended sediment, corrosive to cement. Starting from the fifth sample, it receives a pale yellow colour but there is still no suspended sediment. In November 2006 stream water spills over banks.

Tile drainage water: without odour. The first and the second samples (2004) were opaque, containing suspended sediment, but later samples were clear with only forest detritus floating on the surface.

Sampling point K6

Well water: clear, without turbidity or suspended sediment. The well was originally intended as a source of drinking water.

The results of analyses of historical samples were available for the Železná study area (Špaček 1974; Loskot 1976, 1979; Šmerda 1980). Some of these samples were taken from surface streams during the survey of 1974 with the aim of ascertaining the corrosivity of water to construction materials. The other samples were taken from groundwater because of the planned construction of a well for supplying a nearby farm with water. These results, together with the results of recent sampling, allow us to evaluate the trends of stream and well water quality over time. From the recent sampling data we can also evaluate the trends of the quality of tile drainage water in the Železná study area. An overview of sampling dates is provided in Table 3.

In the Haklovy Dvory area, four samples of tile drainage water were taken for detailed analysis (one sample in Žabovřesky on 27 April 2005 and three samples in Branišov on 17 May 2005) in order to evaluate the difference in quality between the tile drainage water in Haklovy Dvory and in the Železná study area (caused, among other reasons, by different land use and management in the two areas).

RESULTS AND DISCUSSION

In this chapter we evaluate the changes that have occurred over time in the chemical characteristics at the various sampling points, or their variation among samples taken at the same time, with their impact on the qualitative categorisation of the water analysed. Some typical results are presented in graphs, which, in addition to the data for the stream and the tile-drainage water, also indicate the upper limiting values permitted by the surface water quality standard ČSN 75 7221 (1998) and, for comparison, the values found for ground (well) water. It is not, of course, possible to depict all results of particular chemical characteristics for all sampling points. Only the most relevant findings are shown, namely pH, calcium and ammonium for the sampling point K1 and the electrical conductivity, chloride, nitrate, sulphate and phosphate for the sampling point K2. We concentrate on the most significant chemical characteristics, either those for which the limiting values for a qualitative evaluation are set by the standard (ČSN 757221 1998), or those which were also determined in the historical samples (pH, EC, concentrations of Ca^{2+}, Mg^{2+}, SO_4^{2-}, N-NO_3^-, N-NH_4^+ and P-PO_4^{3-}). A comprehensive graphical documentation (45 graphs) and a detailed evaluation of all data is contained in an edited annual report for the fourth year of the QF 3094 research project "Changes in the properties of drained and long-term irrigated soils with their impact on the soil and water conservation" (in Czech) by Vopravil *et al.* (2007). The report is available in the library of RISWC or from the first author of this paper.

Quality of surface water, well water and tile drainage water in the non-intensively managed Železná study area and its development over time

We tried to establish the differences between the quality of tile drainage water and that of the nearest surface water course and to compare the two with the quality of ground (well) water. We also tried to track the development over time of the pollution of tile drainage water, surface (stream) water and ground (well) water. In certain cases, the results of monitoring may lead us to assigning water sampled on different dates to different quality categories. Also the level of chemical pollution in terms of other indicators, not explicitly mentioned in the surface water quality standard, may vary considerably from sampling to sampling. In the first part of this chapter we describe the data from individual sampling points.

Sampling point K1

Stream water.In none of the stream water samples taken at K1 does the pH of surface water display any extreme values, although its fluctuations are not negligible (Figure 3). At the first sampling point K1, in the tributary of the Nivní stream, the historic pH values were 7.5, which is a slightly alkaline reaction. We found the same value during the second sampling in August 2004, i.e., more than three decades later. However, acidification must have occurred before the later sampling (III and IV), with pH reaching 6.6 and later even 6.05, which is a slightly acid reaction. This suggests an increase in acidity or a decline in alkalinity. However, in November 2006 the pH values were higher again, both in stream water (pH 7.2) and in tile drainage water (pH 6.4). It is interesting that even the well water sampled in November 2006 showed an increase in alkalinity, with its pH reaching 7.4. Changes in the concentration of magnesium and, in particular, calcium are approximately correlated with the reduction in alkalinity and the decline in pH values in 2004–2005 and with the increase in pH in 2006–2007 (Figure 3). However, on the fifth sampling date the pH values of the stream once again returned to neutrality (pH = 6.85). The total hardness values of stream water fluctuated between 0.64 and 1.07 mmol(+)/l. The maximum value was found at the second sampling date (in August 2004) and then decreased again. This trend approximately corresponds to the changes in the concentration of Mg^{2+} and Ca^{2+} ions (Figure 4). The electrical conductivity, representing the contents of all dissolved salts, was not determined in the historical samples. Their development over time, starting with second sampling (August 2004), shows a strong correlation with the concentration of Ca^{2+} ions (Figure 4) and partly also of Mg^{2+} ions. The trend in the concentrations of bicarbonate is, as expected, closely connected with the trend of pH values. The increasing concentrations of sulphate and chloride over time (from 7 to 12 mg Cl^-/l, not shown in the graphs) correlate positively with the decrease in pH values (Figure 3) and the increase in acidity. The concentration of potassium ions in all stream water samples was relatively low (2 to 5 mg K^+/l). Similarly, the contents of nitrite were very low (on average, 0.03 mg NO_2^-/l). Likewise, the concentrations of nitrate in stream water were very low (on average, 5 mg NO_3^-/l) and, therefore, below the limit for unpolluted water (3 mg N-NO_3^-/l, which converts to approximately 12 mg NO_3^-/l).

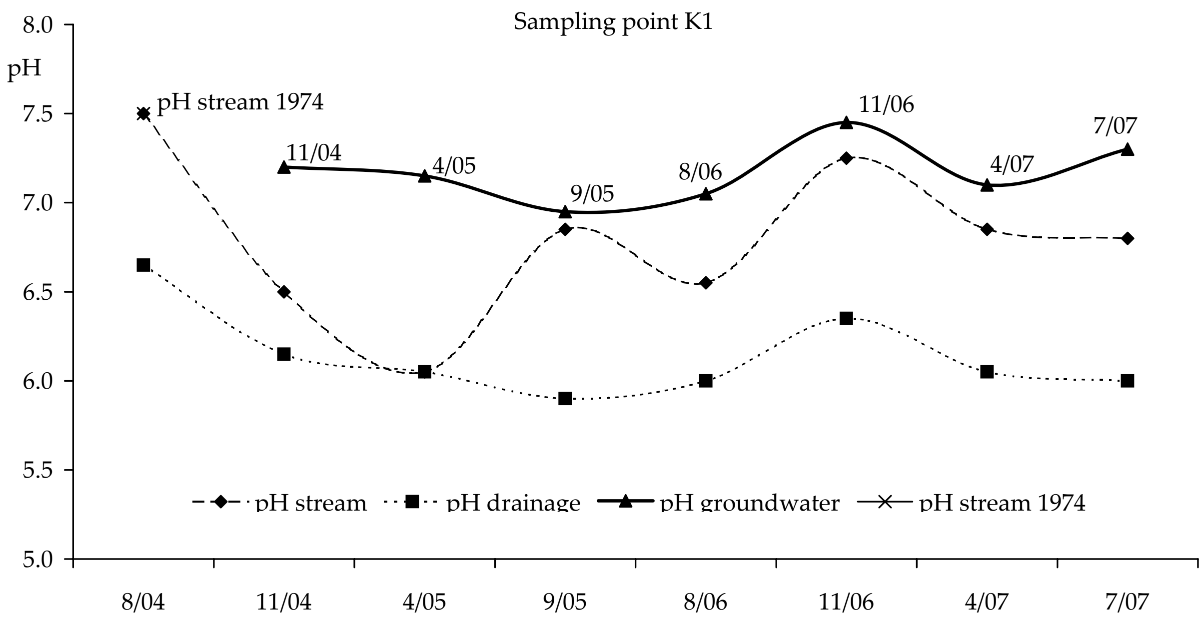

Figure 3. Development of pH values in water of the non-intensively used Železná area

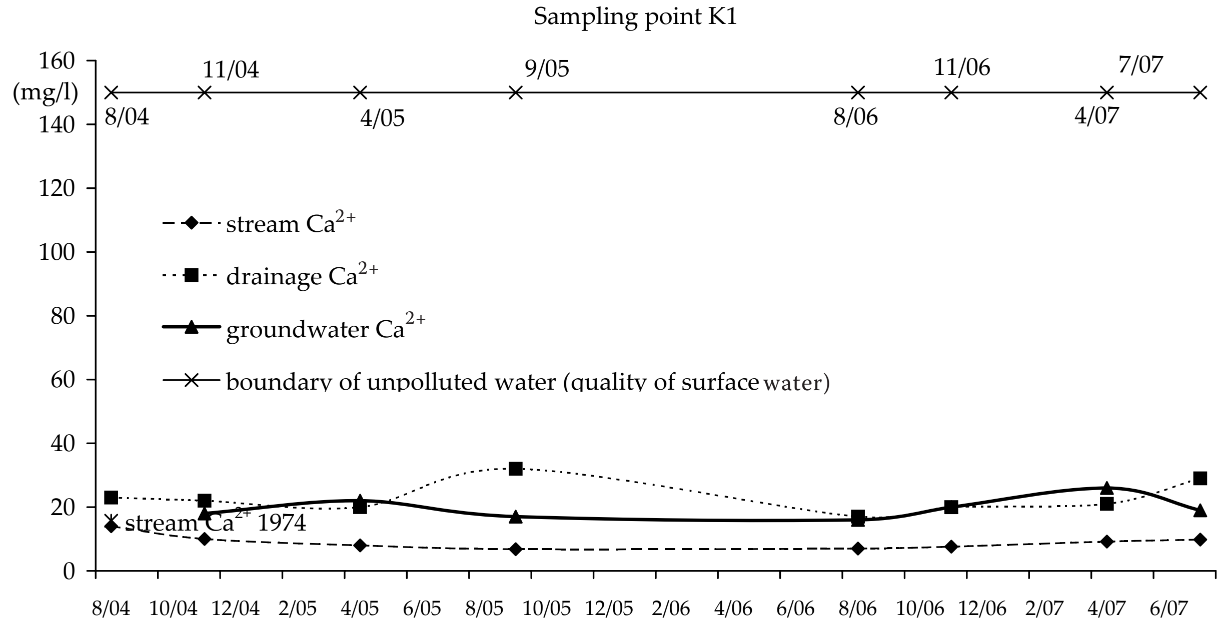

Figure 4. Development of Ca^{2+} concentrations in water of the non-intensively used Železná area

Neither did the contents of phosphate in the stream water exceed the boundary value for unpolluted water (0.05 mg P-PO_4^{3-}/l, which converts to approximately 0.15 mg PO_4^{3-}/l). The variation over time of the concentration of phosphate was all in all negligible. Neither did the contents of ammonium ions reach the threshold value set for unpolluted water (Figure 5). The stream water at the sampling point K1 was therefore definitely unpolluted and continues to be so.

Tile drainage water. Unlike the stream water, the monitoring of tile drainage water did not begin until the start of the recent sampling, beginning in August 2004. The analytical results for tile drainage water differ considerably from those for surface water: its pH is lower (Figure 3), which is associated with the increase in acidity. At the same time, the alkalinity of tile drainage water remains relatively high (1–1.5 mmol/l). Likewise, the total hardness of tile drainage water is higher (especially in the

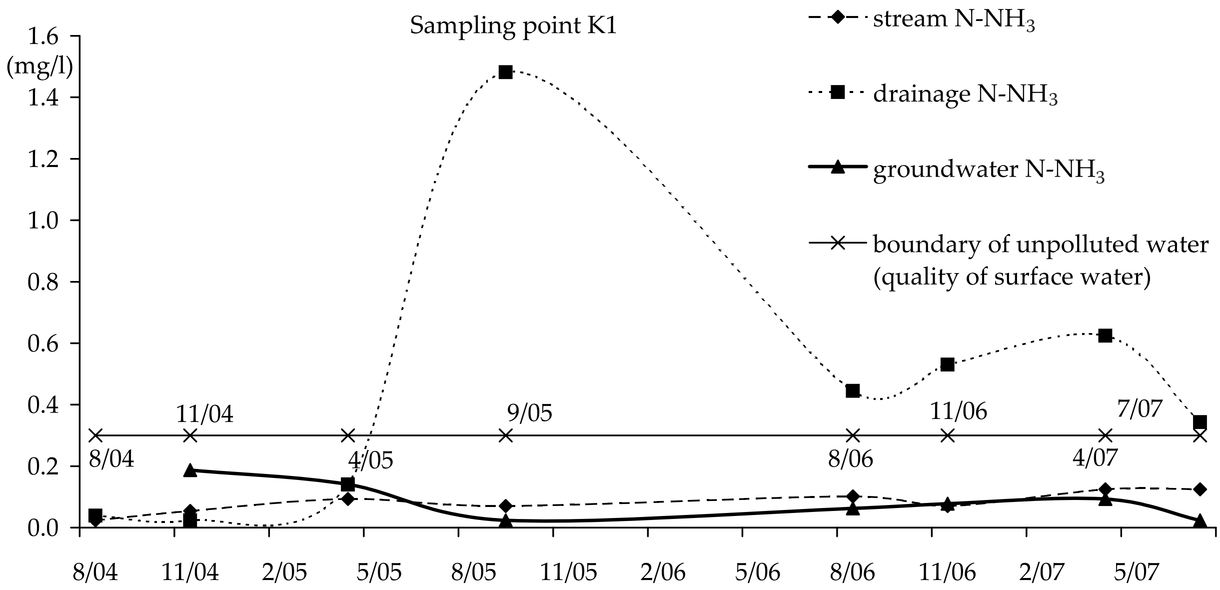

Figure 5. Development of N-NH_3 concentrations in water of the non-intensively used Železná area

more recent samples), which correlates with the higher concentrations of magnesium (not shown in the graph) and calcium (Figure 4). However, even these increased values do not reach the critical level necessary for assigning this water to the slightly polluted category. The same applies to the electrical conductivity values. Even the highest value measured (33.3 mS/m) does not exceed the limiting value for the slightly polluted category (40 mS/m), although it is three times higher than the average electrical conductivity of water in the nearby stream. The high alkalinity of tile drainage water indicates that it contains high amount of bicarbonate (within the range of 60–100 mg HCO_3^-/l). However, the concentrations of sulphate in the tile drainage water do not exceed much those in the stream water. The contents of chloride (on average, approximately 10 mg/l) at first decreased and then, in the later samples, gradually increased. Even in these cases, however, the concentrations were not high enough to indicate pollution of the tile drainage water, nor did the concentrations of K^+ ions in the tile drainage water differ much from the contents of the same in the surface water, fluctuating inconclusively between 2 and 4 mg K^+/l. Only according to the concentrations of phosphate, the quality of the tile drainage water falls into the category II (slightly polluted).

Sampling point K2

Stream water. At the sampling point K2 (Železný A stream), we found, with the exception of the initial (historical) value 6.5, a similar development of pH values over time as in the previous case (K1), although the absolute pH values at K2 are all lower than those at the sampling point K1. Likewise, the trends in acidity and alkalinity have similar patterns as those at K1. The concentrations of magnesium and calcium display similar values and similar trends as those at K1. The same pertains to the total hardness. Only the values of the electrical conductivity (Figure 6) were somewhat lower at K2 compared with those in the water of the Nivní stream – the sampling point K1. The concentrations of bicarbonate fluctuate between 25 and 40 mg HCO_3^-/l and the alkalinity fluctuates between 0.4 and 0.7 mmol/l. Their development over time is correlated to the changes over time in the pH values. The concentrations of chloride (Figure 7), nitrate (Figure 8), sulphate (Figure 9), and nitrite (not shown in graph) did not exceed the boundary values needed to classify the stream water as slightly polluted. According to the concentrations of phosphate (Figure 10), the stream water fell in August 2006 and April 2007 into the category of very heavily polluted waters. At the sampling dates

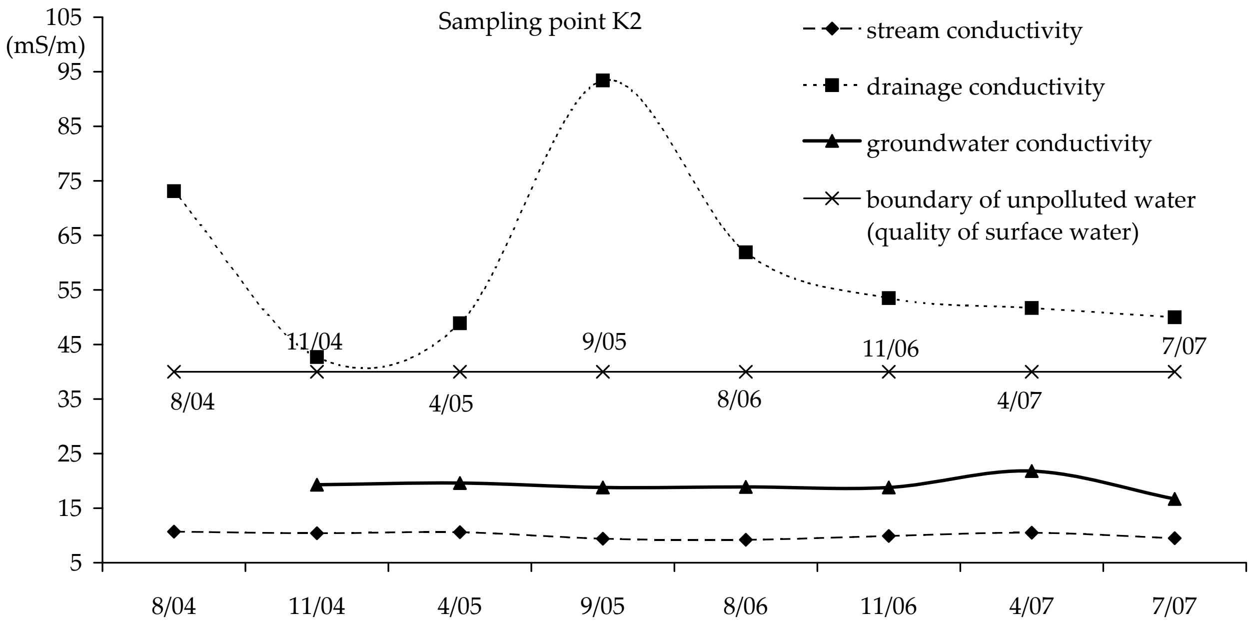

Figure 6. Development of electrical conductivity in water of the non-intensively used Železná area

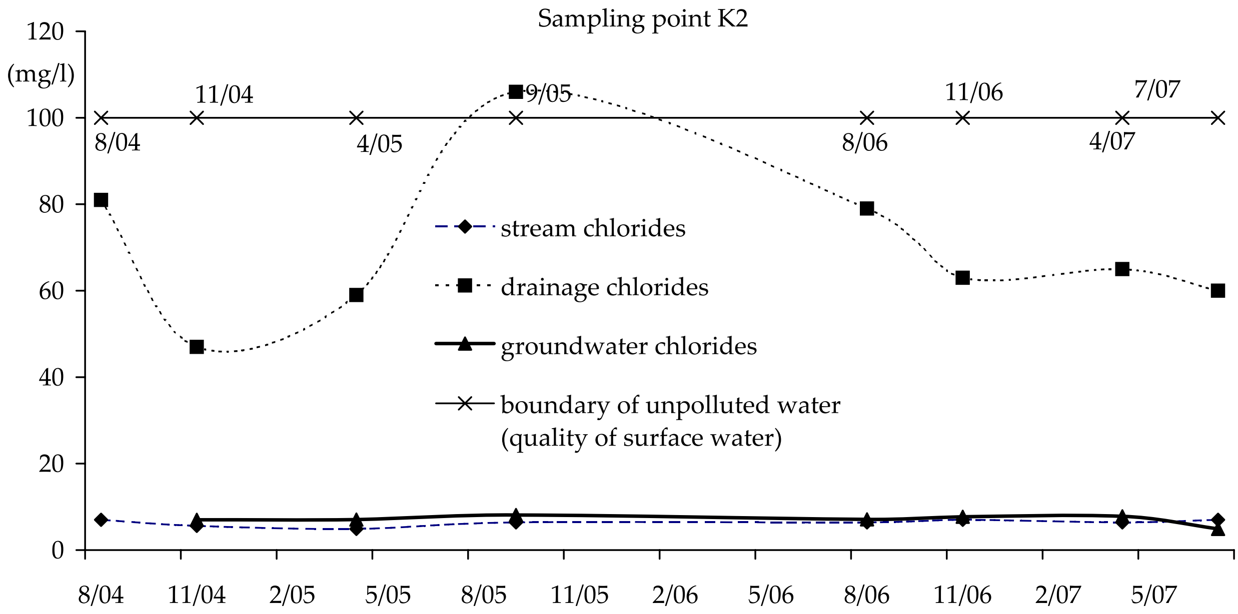

Figure 7. Development of Cl^- concentrations in water of the non-intensively used Železná area

preceding August 2006 and following April 2007, the concentrations of phosphate in the stream water were, however, below the level of slight pollution. Hence, with the exception of the periods with higher contents of phosphate, the stream water was and continues to be unpolluted.

Tile drainage water. The tile drainage water sampled at K2 (near the Železný A stream) displays relatively high values of nearly all its chemical characteristics – the highest among all six tile drainage waters sampled. Its alkalinity (1.85 mmol/l) is higher than that of all other tile drainage and stream waters. Its average concentration of bicarbonate (approx. 105 mg HCO_3^-/l) is likewise higher than the average values at the other sampling points, as are its extremely high values of total hardness (exceeding 3.57 mmol(+)/l). However, due to the absence of threshold values for these characteristics

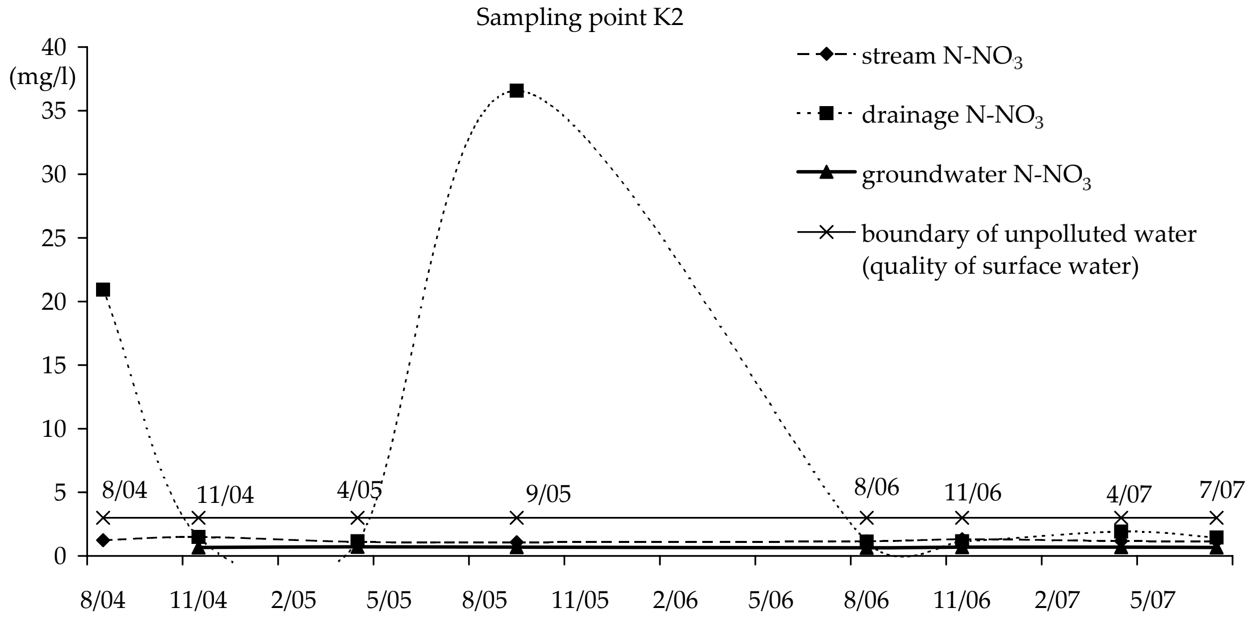

Figure 8. Development of $N\text{-}NO_3$ concentrations in water of the non-intensively used Železná area

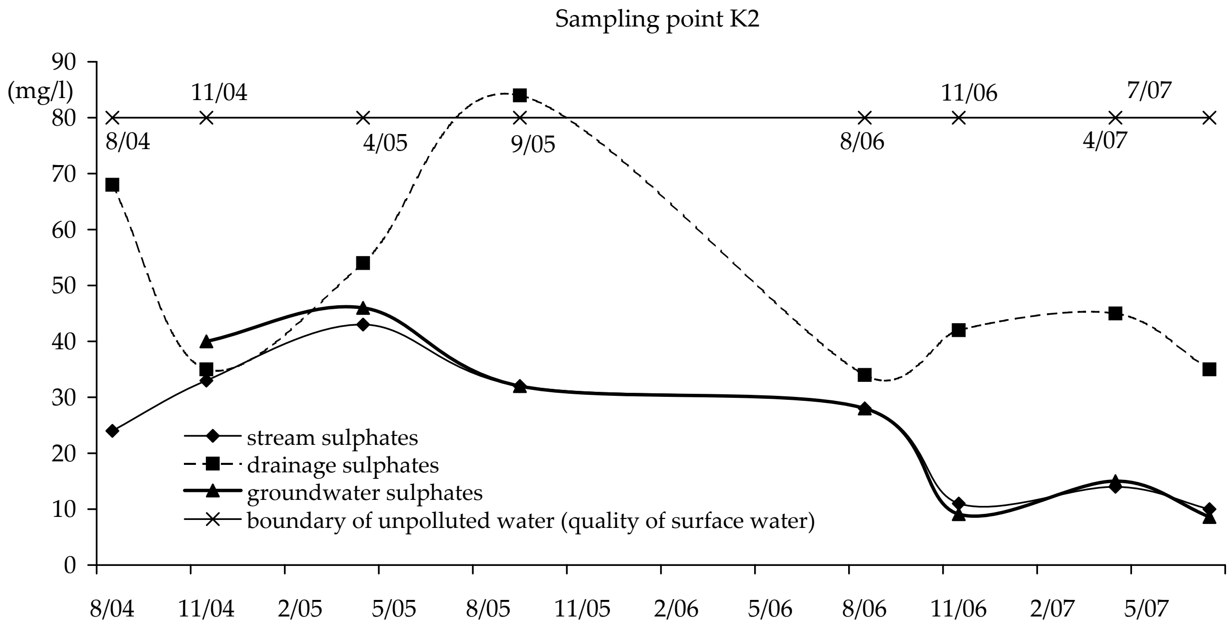

Figure 9. Development of SO_4^{2-} concentrations in water of the non-intensively used Železná area

in the water quality standard (ČSN 75 7221 1998), we cannot categorise the tile drainage water pollution on the basis of these results. Of course, with such high values of the total hardness, it is almost certain that the chemical pollution of this water reached at least the category II (slightly polluted), but more likely the category III (polluted). Similarly, in the case of potassium, we have a good reason to assume that the concentrations approaching 40 mg K^+/l are evidence of at least the medium level of pollution. The concentration of ammonia ions in April 2004 exceeded 0.7 mg NH_4^+/l, which means that, according to ČSN 757221 (1998), this tile drainage water has a medium level of pollution. In the sample taken in 2006 an extremely high content of ammonia was recorded, far higher than in the other samples, suggesting that this tile drainage water was very heavily polluted. According to the sulphate contents (Figure 9), however, the pollution is only slight, whereas the pollution

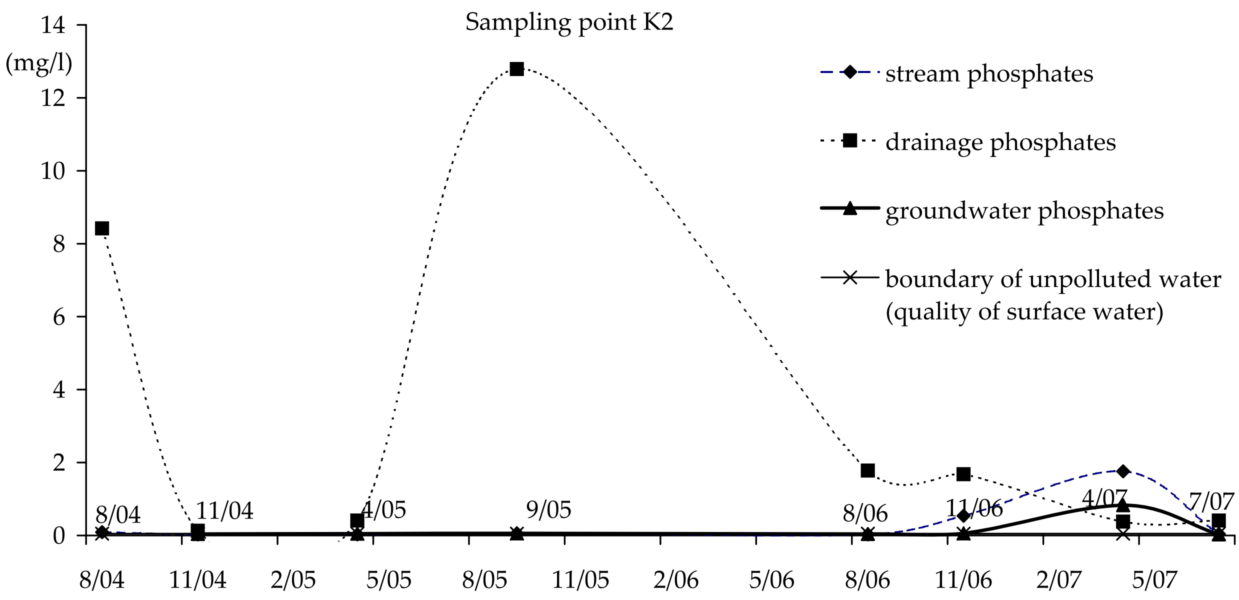

Figure 10. Development of PO_4^{3-} concentrations in water of the non-intensively used Železná area

with phosphates (Figure 10) would, according to the same standard, mostly fall within the medium category, although as early as on the first sampling date of the tile drainage water (in August 2004) a high value over 8 mg PO_4^{3-}/l was found (that is, approximately 2.6 mg P-PO_4^{3-}) and in September 2005 an extremely high concentration of 12.79 mg PO_4^{3-} was measured (which approximately corresponds to 4.3 mg P-PO_4^{3-}) which exceeds the lower limit of the Czech standard for the highest level of contamination – very heavily polluted water. The concentrations of nitrate (Figure 8) reach very undesirably high values, especially during the first and the fourth recent samplings (the latter being 159 mg NO_3^-/l, which converts to more than 35 N-NO_3^-/l). These values, too, assign the category of very heavily polluted water to this sampling point. This categorisation is borne out by the very high contents of nitrite (0.20 to 0.37 mg NO_2^-/l), although we insofar lack any standard threshold figures for the nitrite pollution.

Sampling point K3

Stream water. At the sampling point K3 (the Železný B stream), the pH value 7.0 in the oldest (historical) sample of stream water indicates a neutral reaction. Thirty years later its pH value was even higher (7.45), with a subsequent decrease to 6.0 and then a return to neutral to slightly alkaline reaction. This development of pH is very similar to the changes over time of alkalinity and the content of bicarbonate. This marked variability in pH values can be explained by a very low content of soluble salts and, consequently, low buffering capacity of this relatively clean water. This is also borne out by low values of electrical conductivity and low contents of bivalent cations, with the exception of the second sampling date (August 2004), when also the total hardness in stream water was high (1.71 mmol(+)/l), with a decrease on the further sampling dates down to 0.36 mmol(+)/l. On the same second sampling date, we also found raised concentrations of sulphate, nitrate and phosphate in the stream water, although they hardly reached the threshold dividing unpolluted water from the slightly polluted one. The relatively low concentrations of ammonia ions do not surpass their corresponding thresholds either.

Tile drainage water. Most chemical characteristics of tile drainage water from the vicinity of the Železný B stream (sampling point K3) did not attain any values that would exceed the upper thresholds indicating the slight pollution (except for phosphate). The pH values were, admittedly, all in the interval of slightly acid reaction, but their deviations from the neutral reaction value are, on the whole, small. The alkalinity values varied around 0.7 mmol/l, while the average content of bicarbonate was 40 mg HCO_3^-/l. The trend of acidity was inversely related to the trend of pH values, and the acidity values in general were very low. The total hardness was also very low and declined further between the first (August 2004) and the fourth sampling dates. The concentrations of cations and anions were also very low and, correspondingly the electrical conductivity values were also low, on average only about 11 mS/m). Thus the tile drainage water can be categorised as slightly polluted.

Sampling points K4 and K5

Stream water. The surface water sampling points K4 (Farský A stream) and K5 (Farský B stream) had many common features. The development over time of pH values at both sampling points was very similar and some concurrent values were even identical. The same applies to the values and development of alkalinity. The titration acidity was very low. The trend of total hardness values at both sampling points was decreasing. The pattern of concentrations of cations is similar to that in K2 and K3, with the exception of one case (November 2006) when the concentration of ammonia ions in the Farský B stream reached the threshold for slightly polluted water (0.30 mg/l). Likewise the concentrations of anions (bicarbonate, chloride, phosphate, nitrate and nitrite) found themselves over virtually the whole of the monitoring period within the limits for chemically unpolluted surface water.

Tile drainage water. The two tile drainage sampling points (K4 and K5) showed very similar values for a number of chemical indicators. In the case of pH values, there was a distinct difference between the two sampling points in September 2005, when pH of tile drainage water declined to 5.6 at K4, while its paired value at K5 remained high (6.35). The acidity and alkalinity values were clearly linked to the corresponding pH values. The highest values of alkalinity did not exceed 0.85 mmol/l, while the acidity did not decrease below 0.55 mmol/l. As with the stream water from the Farský stream,

Table 4. Descriptive statistics for all sampling points on study area Železná (SD – standard deviation)

		$N\text{-}NH_3^-$ (mg/l)	$N\text{-}NO_3^-$ (mg/l)	$P\text{-}PO_4^{3-}$ (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	EC (mS/m)	pH
K1/S	median	0.09	0.09	0.01	9.2	28.0	8.0	4.8	12.1	6.8
	SD	0.03	0.81	0.00	1.9	12.5	1.3	0.6	1.4	0.4
	minimum	0.05	0.09	0.01	6.4	13.0	6.8	3.8	9.9	6.1
	maximum	0.12	2.02	0.02	12.0	46.0	10.0	5.8	14.6	7.3
K1/D	median	0.44	0.09	0.01	14.0	28.0	21.0	11.0	22.4	6.1
	SD	0.48	1.65	0.03	4.8	12.5	5.4	4.1	4.9	0.1
	minimum	0.03	0.09	0.01	9.9	15.0	17.0	9.1	19.2	5.9
	maximum	1.48	4.60	0.09	24.7	44.0	32.0	21.0	33.3	6.4
K2/S	median	0.05	0.09	0.01	6.4	28.0	7.0	3.9	9.9	6.6
	SD	0.04	0.67	0.21	0.8	12.8	2.3	0.3	0.6	0.3
	minimum	0.03	0.09	0.01	4.9	10.0	5.0	3.6	9.2	6.5
	maximum	0.12	1.50	0.58	7.0	43.0	12.0	4.4	10.6	7.3
K2/D	median	1.26	1.45	0.14	63.0	42.0	42.0	15.0	51.7	7.0
	SD	1.72	13.52	1.51	19.1	17.8	7.0	2.5	16.9	0.2
	minimum	0.25	0.09	0.04	47.0	34.0	37.0	13.0	42.7	6.8
	maximum	5.14	36.57	4.22	106.0	84.0	58.0	20.0	93.4	7.4
K3/S	median	0.09	0.09	0.01	5.6	26.0	5.4	2.9	7.6	7.0
	SD	0.04	0.64	0.01	0.9	14.0	3.1	0.3	1.0	0.4
	minimum	0.03	0.09	0.01	4.2	10.0	0.4	2.6	7.5	6.0
	maximum	0.14	1.59	0.05	7.0	42.0	9.0	3.3	10.1	7.3
K3/D	median	0.05	1.20	0.02	4.9	30.0	7.0	4.9	11.3	6.1
	SD	0.04	0.77	0.13	1.7	17.3	1.7	0.4	0.4	0.3
	minimum	0.03	0.09	0.01	4.2	10.0	5.7	4.3	10.8	5.8
	maximum	0.14	1.79	0.34	9.1	55.0	11.0	5.6	11.9	6.8
K4/S	median	0.05	1.93	0.01	13.0	27.0	9.6	4.4	12.1	6.7
	SD	0.02	0.89	0.00	1.5	17.1	2.4	0.1	0.5	0.2
	minimum	0.04	0.09	0.01	11.0	10.0	8.0	4.1	11.7	6.6
	maximum	0.09	2.99	0.02	15.0	55.0	15.0	4.5	13.1	7.2
K4/D	median	0.12	0.09	0.03	7.0	28.0	11.0	5.8	13.0	6.0
	SD	0.06	0.72	0.02	1.2	17.3	1.9	1.6	1.6	0.3
	minimum	0.10	0.09	0.02	5.6	13.0	8.2	5.1	12.4	5.6
	maximum	0.28	1.61	0.07	9.2	60.0	14.0	9.6	17.2	6.4
K5/S	median	0.09	0.09	0.02	13.0	30.0	10.0	4.9	13.7	6.6
	SD	0.08	0.85	0.02	1.8	18.7	1.6	0.4	1.3	0.2
	minimum	0.07	0.09	0.01	12.0	10.0	8.2	4.6	12.5	6.4
	maximum	0.30	1.93	0.06	17.0	58.0	13.0	5.6	16.2	6.9
K5/D	median	0.07	0.09	0.03	5.7	28.0	6.0	2.5	8.0	6.6
	SD	0.02	0.46	0.01	2.6	13.7	4.4	0.4	1.9	0.3
	minimum	0.03	0.09	0.01	3.5	10.0	0.4	1.7	6.4	6.0
	maximum	0.08	1.31	0.03	9.9	44.0	12.0	2.9	10.8	6.6
K6/W	median	0.08	0.09	0.02	7.1	28.0	19.0	8.4	18.9	7.2
	SD	0.06	0.00	0.10	1.1	14.5	3.4	2.0	1.5	0.2
	minimum	0.03	0.09	0.01	4.9	10.0	16.0	5.6	16.7	7.0
	maximum	0.19	0.09	0.27	8.1	46.0	26.0	12.0	21.8	7.5

neither of the two sampling points of tile drainage water displayed any extreme values of any of the chemical indicators monitored. This applies to the concentrations of cations (including ammonia ions), as well anions (including bicarbonate), total hardness and electrical conductivity.

Sampling point K6

The chemical characteristics of groundwater in the Železná study area was assessed from the quality of the well water at the sampling point K6. The values of chemical indicators measured there differ markedly from the corresponding values found in the stream and the tile drainage waters. During the monitoring, we found relatively high levels of alkalinity (up to 1.9 mmol/l) and relatively high total hardness (up to 2.07 mmol(+)/l) which is reflected by relatively high concentrations of bivalent cations – up to 25 mg Ca^{2+}/l (Figure 4) and 12 mg Mg^{2+}/l. The concentrations of these cations in the well water are lower that those in the tile drainage water, but in some cases slightly exceed the corresponding concentrations in the stream water. In no case, however, do they exceed the standard lower threshold values for slightly polluted surface water. The concentrations of nitrate (on average, 5 mg/l) lie within the standard range defining unpolluted water (Figure 8). Likewise, the concentrations of nitrite (not shown), for which we have so far no standard concentration limits, are at a very low level (0.03 mg NO_2^-/l). Neither does the concentration of ammonia ions 0.2 mg/l indicate any chemical pollution of the well water. Throughout the most of the monitoring period, the contents of phosphate in the well water (Figure 10) did not exceed the upper limit for unpolluted water, while the last two samples, especially the one taken in April 2007, attain surprisingly high concentrations of phosphate (0.80 mg PO_4^{3-}/l, i.e. approximately 0.40 mg P/l, in April 2007). That would correspond to at least a medium level of the phosphate pollution. It is difficult to find a satisfactory explanation for this sudden rise of the concentration of phosphate. It appears that soil erosion must have occurred or the phosphate could be washed away from the original manure heap.

A common overview of data is provided by Table 4, which contains basic descriptive statistics of the chemical characteristics measured for all sampling points over the entire period of observation (including the historical data).

We may state that, in most cases, the stream water and tile drainage water monitored in the Železná area, even when its flow rates were low, conforms to the water quality standard's definition of unpolluted or slightly polluted surface water. A singular and unwelcome exception to this rule is the tile drainage water at the sampling point K2 and, partly, also the stream water at this sampling point, where serious pollution has certainly occurred, as is shown by the values of several chemical indicators (nitrate, phosphate and ammonia ions). A probable cause of this pollution was the farmyard manure heap in the nearby field about 300 m from the sampling point. The other tile drainage waters in the non-intensively exploited soils of the Železná study area conform without exception to the relatively strict criteria of the surface water quality standard ČSN 75 7221 (1998).

As for the increased phosphate concentrations at K6 towards the end of the period, it follows that their increase was observable not only in the well water but also in the tile drainage water and the stream water at individual sampling points, but not at the same time, and with varying intensity. At the sampling point K2, the increase of phosphate concentration was most intensive as early as April 2005, while at the points K3 and K4 the concentration of phosphates did not culminate until 2006. At the sampling point K5 the increase in phosphate concentration was not very high and developed more gradually, but then it lasted for a relatively long time, from spring 2005 until November 2006, while the ground water was affected later (in April 2007).

Chemical characteristics of drainage water in the Haklovy Dvory study area

Here we can only present the characteristics of four samples of drainage water (Table 5), taken, respectively, on 27th April 2005 at Žabovřesky and on 17th May 2005 at three other sites in Branišov (see Figure 2).

Overviewing the results of analyses of these four samples of drainage water shows us that some of the chemical characteristics vary relatively little, while the variation of others is surprisingly high. For example, in terms of pH values, which indicate that in all cases the water is only slightly acidic, the differences among the sites are hardly significant. The same applies to the electrical conductivity (with the exception of the sample from Žabovřesky)

Table 5. The chemical characteristics of drainage water taken in the Žabovřesky and Branišov sites of the Haklovy Dvory area

Site	pH	$N\text{-}NH_3$ (mg/l)	$N\text{-}NO_3$ (mg/l)	PO_4^{3-} (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	EC (mS/m)
Žabovřesky	6.6	0.10	28.3	0.27	52	86	66	31.0	70.0
Branišov 1	6.8	0.27	34.3	0.1	43	79	62	28.0	68.4
Branišov 2	6.6	0.10	25.1	0.16	71	100	76	42.0	70.8
Branišov 3	6.8	0.52	17.0	0.91	42	96	82	49.0	71.1

and to the acidity. There is also a relatively high degree of similarity among the concentrations of calcium, chloride and nitrate at different sampling points. By contrast, large variation is found among the concentrations of potassium, nitrite, ammonium nitrogen and phosphate. If we compare the values found with the corresponding thresholds of surface water quality standard categories, we discover that the tile drainage water analysed was relatively clean and of good quality according to some criteria, while it comes out as polluted or even very heavily polluted according to other criteria. For example, the water from Branišov 3 would be categorized as unpolluted or only slightly polluted, based on the concentrations of chloride, sulphate and ammonia ion. The water from Žabovřesky would also fall within the quality class II (slightly polluted) according to these criteria. By contrast, the very high concentrations of nitrates are almost startling. Their contents in all samples significantly exceeds the lower threshold value for the very heavily polluted water (pollution category V), i.e. 13 mg $N\text{-}NO_3^-$/l, which converts to 57 mg NO_3^-/l. According to phosphate, the water from Žabovřesky falls within the pollution category II, i.e. slightly polluted. The samples from Branišov1 and 2 would even correspond to category I, while the sample from Branišov 3, because of its elevated concentration of 0.91 mg PO_4^{3-}, i.e. 0.30 mg $P\text{-}PO_4^{3-}$/l, falls within the category III – moderately serious phosphate pollution. Likewise, a comparison of threshold values for the electrical conductivity with its actual values found in the tile drainage water shows that this water falls within the categories II and III (slightly polluted to medium polluted).

Our interpretation of these facts is that the intensive land management in the Haklovy Dvory area, comprising regular ploughing, the use of organic and mineral fertilizers and liming (although not very intensive over the last decade) have probably caused a release of a part of the soil nutrients in their mobile forms, accessible to plants, and that there may also have been erosive washout and associated loss of phosphate sorbed on the detached soil particles, as well as washout of nitrate and nitrite and the soil organic matter, which altogether caused contamination of tile drainage water. At the same time, however, it should be noted that the relatively high concentrations of some of the mentioned chemical contaminants in the Haklovy Dvory area persist even when the flow rates are high, in contrast to the Železná study area. Hence, worsened tile drainage water quality in the Haklovy Dvory area is not due to low flow rates, but due to a direct impact of land management.

CONCLUSIONS

Monitoring of the quality of tile drainage water and a comparison of its quality with that of surface water, as well as a comparison of the changes over time in the quality of tile drainage water in the areas where the soil is non-intensively used (meadows, pastures, permanent grasslands, such as in the Železná area) with the tile drainage water quality in the areas where the soil is used intensively (such as the arable land in the Haklovy Dvory area) was carried out within the framework of research into the changes in various characteristics of tile drained soils and their impact on soil and water conservation.

In the areas of pastoral agriculture, with a very few exceptions, no pronounced chemical pollution of the tile drainage water was found, despite the fact that the drainage water flow rate was usually relatively low. By contrast, in an area with intensive agricultural activity, the chemical pollution of some samples of tile drainage water was relatively high, in some cases high enough to place the tile drainage water in the heavily or very heavily polluted surface water categories, despite relatively high flow rates. We can therefore conclude that the pollution of drainage water is directly connected to the type of farming on the drained soil. In spite of relatively low frequence of sampling, we were able to identify certain trends in the water quality of the model areas monitored. In order to verify these trends, the authors are going on with the sampling of drainage, surface and well water.

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