

The Impact of Deforestation on the Quality of Drainage Water in the Železná Model Area

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Abstract

The article is focused on the changes in soil characteristics caused by the drainage of agricultural soils in the Czech Republic. The basis of the research was to compare current state with the state before drainage using available historical data. To resolve the subject of the research, two smaller study areas with different soil uses were chosen. The Haklovy Dvory area is an arable land that is intensively used. The other area is used mainly for grazing (extensively) and it is called Železná study area. In many cases, historical data regarding the quality of surface water and groundwater (well water) in the two areas is readily available; therefore, the same approach was taken for monitoring the current quality of drainage water. Several chemical indicators were measured in the water: pH, alkalinity-acidity, overall hardness, concentration of selected cations (magnesium, calcium, potassium, ammonia), concentration of bicarbonates, nitrates, nitrites, sulphates, phosphates, chlorides and the electrical conductivity of the water. During the entire course of the monitoring, no serious water pollution was found in Železná study area (with the exception of one sample point). In case of the intensively managed Haklovy Dvory study area, a significant pollution in all drainage water samples was confirmed. We can safely formulate a hypothesis that the drainage water quality is related to the type of agriculture procedure practiced on the land. Mainly the intensive type of agriculture, because of the use of fertilizers, has a negative impact on drainage water quality, and subsequently on the quality of surface watercourses.

Keywords

Water Quality, Drainage, Land Use, Soil

1. Introduction

This contribution arises from a research assignment dealing with the adverse changes in soil properties and the negative impact on chemical and physical soil characteristics that have occurred in agricultural soils as a result of their drainage. These changes are one example of the negative impact that intensive agriculture has on the soil and on the environment in general. The most pronounced changes caused by the intensification of agricultural production include those occurring both in the soil, and subsequently those in surface water and groundwater, whether they are the result of extensive and often unjustified drainage in past decades, or, on the other hand, the result of long-term irrigation, especially where unsuitable and sometimes highly polluted river water has been used. Even though the extensive existing drainage systems, which in our country date from the Communist era, are, as a rule, not maintained today and also often function poorly, their negative impact on the quality of both soil and water may still persist. Based on the specifications of the analytical data, the systematically collected samples of surface and drainage water were assigned to the appropriate quality categories according to the valid norm for surface water quality for the Czech Republic—based on the threshold values for the most significant chemical characteristics [1].

The European ICID regional conference held in Brno in 2001 focused intensively on the following issues: the principles of EU water management and agricultural policy, the transformation and reconstruction of existing irrigation and drainage systems in Central and Eastern Europe and their appropriate economic and environmental utilization, as well as the minimization of the impact of extreme hydrological phenomena with the aim of achieving the sustainable use of both soil and water. The papers presented at the conference that we found the most interesting and stimulating for our work were those of the following authors [2]-[10]. These papers dealt with, among other things, the possible dramatic changes in soils caused by the construction of irrigation and drainage systems, and their long-term intensive use.

Our attempt to solve the issues mentioned above is based on a comparison of the current state of the soils with their state before irrigation [11] and we evaluate the most significant changes in the soils' characteristics. Thanks to the database maintained by VÚMOP (The Research Institute for Soil and Water Conservation in Prague, Czech Republic), we have at our disposal extensive and essential historical analytical data about the soils [11] [12] [13] [14] [15]. Additionally, from our study area we have "historical" data about the quality of surface water and groundwater (water from wells) [16] [17]. The source of our "current" up-to-date data comes from the systematic monitoring of drainage water quality which we have been carrying out since 2004. By synthesizing information found in these two databases (the historical one and the current one), we have created an extensive set of information about water quality in the study areas, in which the current data (which is constantly being updated) is compared

with the historical data regarding drainage water, surface water (stream) and groundwater (well).

2. Materials and Methods

2.1. Soil and Hydrological Characteristics of the Model Area

The Železná model area is located in the Domažlice district on the border with Germany (GPS position: 49 deg. 34' - 35' North, 12 deg. 34' - 36' East). From a geological point of view, it belongs to the crystalline or moldanubic Bohemian Forest formations (in Czech: Český Les) with a predominance of cordieritic gneiss and silmanite-biotitic migmatized paragneiss with cordierite. The area falls within the moderately cool and damp climatic region. The annual average temperature is between 5°C and 6°C. Average annual precipitation is 700 - 800 mm.

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. The drainage network is comprised of streams (the Nivní, Farský and Lesní streams) and artificial watercourses. The study area lies within the drainage basin of the Danube. In the 1980s, the area was drained systematically using pipe drainage, with the aim of improving the physical state of the soil and the water regime of the agricultural land, and improving and increasing agricultural production. A detailed hydrogeological survey was carried out in the 1970s by the State Amelioration Administration [17] to provide the groundwork for a drainage system. After the drainage was complete, the agricultural areas were used as arable land, but today they are used for pastures.

The Haklovy Dvory study area lies within the České Budějovice basin, to the northwest of České Budějovice. It is a flat area with little variation in relief. It lies at altitudes ranging from 378 m to 438 m above sea level. Its geological underlier consists of sandy, clay-like or mixed tertiary lake deposits. A common characteristic of these deposits is a lack of plant nutrients, as well as generally unfavorable chemical and physical characteristics. The soil cover is most frequently comprised of Haplic Stagnosols and, to a lesser extent, Stagnic Combisols. The hydrological conditions of the study area are determined by the climate, the matrix substrates and the relief. As a result, an excessive amount of water is held in the soil profile and there is temporary waterlogging and gleying of the soils. For that reason, a systematic pipe drainage network was built in the 1980s, most of which still functions today. The aim of the drainage system was to improve the physical condition of the soils, and to create more favorable conditions for intensive agricultural production (Figure 1).

2.2. Chemical Characteristics of Surface Water Quality

The state of the surface water quality is defined by the threshold values of select

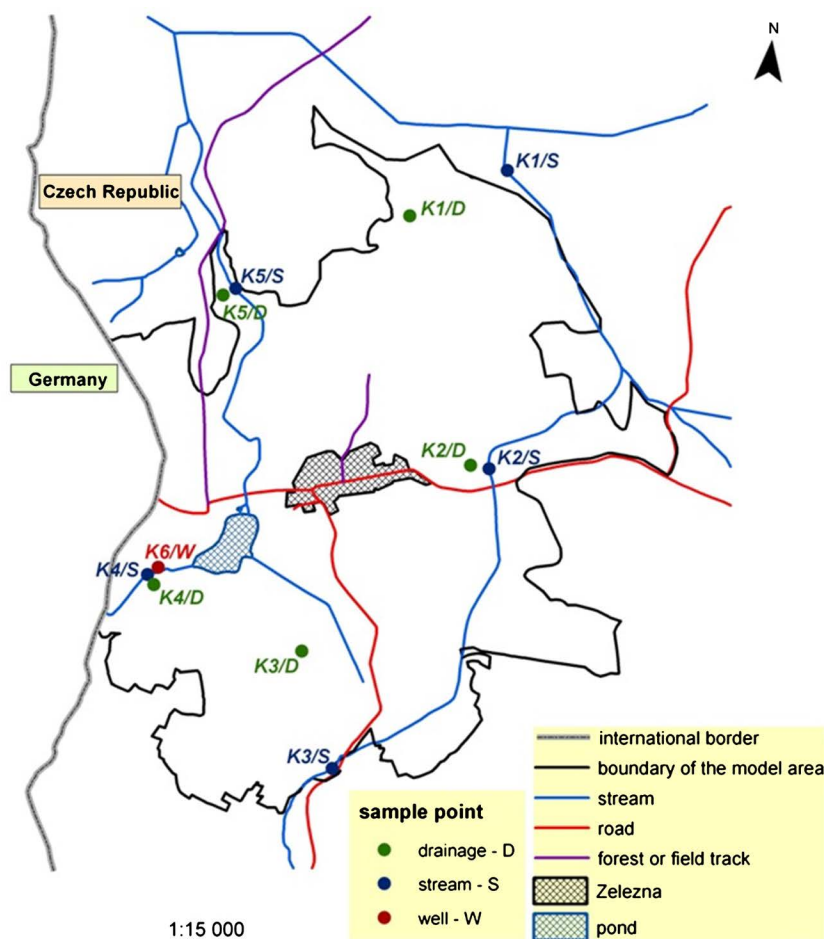


Figure 1. The Železná model area with its sample points.

chemical characteristics set out in Czech Norm No. CSN 757221 (Table 1) [1]. The norm applies to the uniform determination of running surface water quality. Elements present in the water are analyzed by absorption spectrophotometry. According to the concentration of the most important cations (magnesium, calcium and ammonia) and anions (sulphates, chlorides, phosphates and nitrates), and electrical conductivity E.C., the norm distinguishes five qualitative categories of pollution. Unfortunately, it does not make specific references to a number of other indicators which are also, in their own way, important and certainly significant from the perspective of health and hygiene. For example, it does not define the range of pH values for polluted water, nor does it consider the level of acidity-alkalinity. It also fails to define the overall hardness of surface water, the limit concentrations of certain important ions (potassium, bicarbonate), and even the concentration of nitrites, which is one of the most important criteria for evaluating drinking water quality.

During the course of our monitoring of the changes in soil and water chemistry caused by drainage and the subsequent use of the soil, we did, however, monitor changes occurring over time in the above-mentioned indicators too, although the existing quality norm has yet to set limits for their values in surface

Table 1. Limit values for concentrations of ions (mg/l) of electrical conductivity E.C. (mS/m) for the classification of surface water according to quality [1].

Chemical Property	Quality class of surface water and its classification					Specified by norm
	I.	II.	III.	IV.	V.	norm
	<i>unpolluted</i>	<i>slightly polluted</i>	<i>polluted</i>	<i>heavily polluted</i>	<i>very heavily polluted</i>	
N-NH ₃	<0.3	<0.7	<2.0	<4.0	>4.0	ISO 11732
N-NO ₃	<3	<6	<10	<13	>13	EN 757453
P-PO ₄ ³⁻	<0.05	<0.15	<0.4	<1.0	>1.0	EN 1189
Cl ⁻	<100	<200	<300	<450	>450	ISO 6058
SO ₄ ²⁻	<80	<150	<250	<400	>400	ISO 9280
Ca ²⁺	<150	<200	<300	<400	>400	ISO 6058
Mg ²⁺	<50	<100	<200	<300	>300	ISO 6059
E.C.	<40	<70	<110	<160	>160	EN 27885

or drainage water. Until the quality norm for surface water is changed, we cannot reasonably judge how much the increase in their concentration shifts the quality of stream or drainage water into a lower category, even when there is considerable fluctuation in the values of those indicators.

In **Table 1**, we present the various norms which determine the methodology for surface water analysis. The principles of the most important specifications are as follows: ammoniac nitrogen is analyzed spectrophotometrically using a Nessler reagent, nitrate and nitrite nitrogen is analyzed using the automated spectroscopic method, chlorides are analyzed argentometrically, sulphates are analyzed gravimetrically (such as BaSO₄), phosphates are analyzed spectrophotometrically with ammonium molybdenum, calcium is analyzed volumetrically with chelaton III, and magnesium is analyzed differentially from the overall hardness and calcium cation content.

For the other chemical characteristics, which are, in this case, still only supplementary, we carried out analytical specifications according to the following norms: pH potentiometrically [18], alkalinity or ANC (acid neutralizing capacity) by titration using phenolphthalein and methyl orange as indicators [19] potassium using flame testing/absorption spectrophotometrically [20] and nitrites spectrophotometrically [21].

In the Železná model area, we collected water samples from six sample points (K 001 to K 006). Essentially, eleven water samples were always collected simultaneously. They were always paired samples: stream - drainage. The last sample (K 006) was unpaired and collected from a well at depth of 0.3 m under the water level (corresponding to the groundwater water level)—see **Figure 1**. The depth of sampling points K 001 - K 005 was 0.3 m in case of surface water, and 0.8 m in case of samples gathered from functioning drainage pipe. 88 samples were collected in total.

Sample Point K 001:

Tributary of the Nivní stream; clear water, colorless, no sediment, with leaching and carbonate aggressivity towards cement;

Drainage Water: The first three samples showed functioning drainage with clean water. From the third sample onwards, the water was turbid and odoriferous, and from the fifth sample, it contained rust sediment. From the sixth sample, there was oil on the surface and the water was almost stagnant.

Sample Point K 002:

Železný A Stream: with clear, colorless water, also with leaching, acidic and carbonic aggressivity towards cement; since July 2007 the water has been of a light yellow color;

Drainage Water—originally slightly flowing, colorless clear water, but from the fourth sample, it was found to be turbid, odoriferous and containing sediment. In a field about 300 meters above the sample point, a manure heap had been disturbed. The water in the shaft is almost stagnant.

Sample Point K 003:

Železný B Stream: clear, colorless water, also with leaching and carbonic aggressivity towards cement;

Drainage Water—colorless, without odor or sediment. From the fourth sample, it was found to have signs of a ferrous coating; slightly colored and containing foam since spring 2007.

Sample Point K 004:

Farský A Stream: colorless, clear water without odor or sediment. From the fourth sample found to be slightly overflowing, raising the level in the drainage well. Displays aggressivity towards cement (carbonic and leaching);

Drainage Water: Colorless, clear, odorless. From the fourth sample, it was found to have a ferrous coating. From the fifth sample, it was found to have oily patches (perhaps diesel fuel); since spring 2007, it has been found to contain sediment and show a light yellow coloration.

Sample Point K 005:

Farský B Stream: clear, colorless water, without odor or sediment, aggressive towards cement. From the fifth sample, it was found to be pale yellow in color without sediment. In November 2006, it was overflowing;

Drainage Water: without odor. In the first and second samples (2004), it was found to be opaque and containing sediment, but in later samples it was clear, with forest detritus floating on the surface.

Sample Point K 006:

Well containing clear water, without turbidity or sediment. Originally intended as a source of drinking water.

The results of the analysis of the original (historical) samples were available for the Železná area. Some of them were collected from surface water during the hydrogeological survey of 1974, with the aim of ascertaining the possible aggressivity of the water towards construction. The other samples were collected

from groundwater due to the construction of a well for supplying a farm with water. This allows us to evaluate changes over time (or, at least, their trends) in the quality of stream and well water, as well as changes in the quality of drainage water (see **Table 2**) from the second sample (August 2004) onward.

In the Haklovy Dvory area, four drainage water samples were collected for detailed analysis and to serve as supplementary material for the evaluation of the difference in quality between the drainage water in Haklovy Dvory and in the Železná study area (among other reasons, because of the different land management in the two areas).

3. Results and Discussion

In this chapter, we will evaluate the changes in chemical characteristics that have occurred over time at the various sample points, as well as their changes in the various samples collected at the same time, with an analysis of their impact on the qualitative categorization of the water. The results are documented in the relevant graphs, which, apart from the stream and drainage water data, also indicate the upper limit values permitted by the norm for the given characteristics, and, for comparison, the relevant values specified for groundwater (well). Due to limitations on the length of this publication, it is not, of course, possible to depict all the results of the specifications of all the monitored chemical characteristics from the various sample points in graph form. The number of graphs had to be greatly reduced, and only the most interesting findings are shown. Although we are attempting to give a comprehensive appraisal of the findings, it was necessary to concentrate primarily on the most significant chemical characteristics, that is to say, those for which there are limit values for the qualitative evaluation of surface water set by the norm, or those which were also specified for the initial,

Table 2. Dates of water samples collected for analysis.

No.	samples from:
I.	Original “historical” samples from approximately thirty years ago (1974)
II.	August 2004
III.	November 2004
IV.	April 2005
V.	September 2005
VI.	August 2006
VII.	November 2006
VIII.	April 2007
IX.	July 2007

Note: In the first, original “historical” samples collected in 1974, the following specifications were implemented: pH, acidity, alkalinity, overall hardness, and the concentration of magnesium, potassium, bicarbonate and sulphate ions, the threshold value of several of which is not determined by the quality norm). In the “current” samples (numbers 2 to 9), in addition to those specifications, the following characteristics were also specified: electrical conductivity (E.C.), chlorides, potassium, nitrites, phosphates and ammoniac nitrogen.

so-called “historical” samples (pH, E.C., concentrations of Ca^{2+} , Mg^{2+} , SO_4^{2-} , N-NO_3^- , N-NH_4^+ , P-PO_4^{3-}). The complete graphic documentation (45 graphs) and a detailed evaluation of all the data is presented in the edited annual report for the fourth year of the QF 3094 project entitled “Changes in the properties of drained and long-term irrigated soils with their impact on the soil and water conservation” (in Czech language) by J. Vopravil *et al.*, 2007; the report is available in the VÚMOP library or directly from the research project leader.

3.1. Surface, Well and Drainage Water in the Extensively Managed Železná Study Area and the Development of Their Chemical Characteristics over Time

By analyzing drainage and surface water samples, we have attempted to establish the difference between the quality of drainage water and that of the nearest surface watercourse, and what development occurs in the pollution of drainage water or, as the case may be, in surface water (stream) and groundwater (well). We assumed that in certain cases throughout the course of our monitoring, drainage and the various possibilities of pollution might lead us to reassign water to a different quality category, or that the level of chemical pollution might change. It is also interesting to compare surface water quality (both stream and drainage water) with that of groundwater (well).

Sample Point K 001

stream water

In none of the watercourses does the pH reaction of the surface water display any extreme values, although its fluctuations are not negligible (Figure 2). At the first sample point, in the tributary stream of the Nivní stream, the so-called historic values were pH = 7.5—a slightly alkaline reaction. We also measured this value in the second sample (in August 2004—more than three decades later). However, in the later samples (no. 3 and 4), acidification had occurred, reaching pH 6.6 and later even pH 6.05; a slightly acidic reaction. This suggested an increase in acidity or a decline in alkalinity. However, in November 2006, there was an increase in the pH value of both stream water (pH 7.2) and drainage water (pH 6.4). It is interesting to note that, in well water, the sample from November 2006 also showed an increase in alkalinity, and its pH reached 7.4. Changes in the concentration of magnesium ions and, in particular, calcium ions are in approximate correlation 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, in the fifth sample, the pH values of the watercourse once again returned to neutrality (pH 6.85). The overall hardness values of stream water fluctuated in the region of 1.8 to 3 German degrees. The maximum value was found in sample no.2, after which it decreased again. The trend approximately corresponds to the changes in the concentration of Mg^{2+} and Ca^{2+} ions (Figure 3). The electrical conductivity values expressing the salinity of the water (the dissolved salt content) were not specified in the “historical” samples, however, their development starting with sample no.2 shows a strong correlation with the

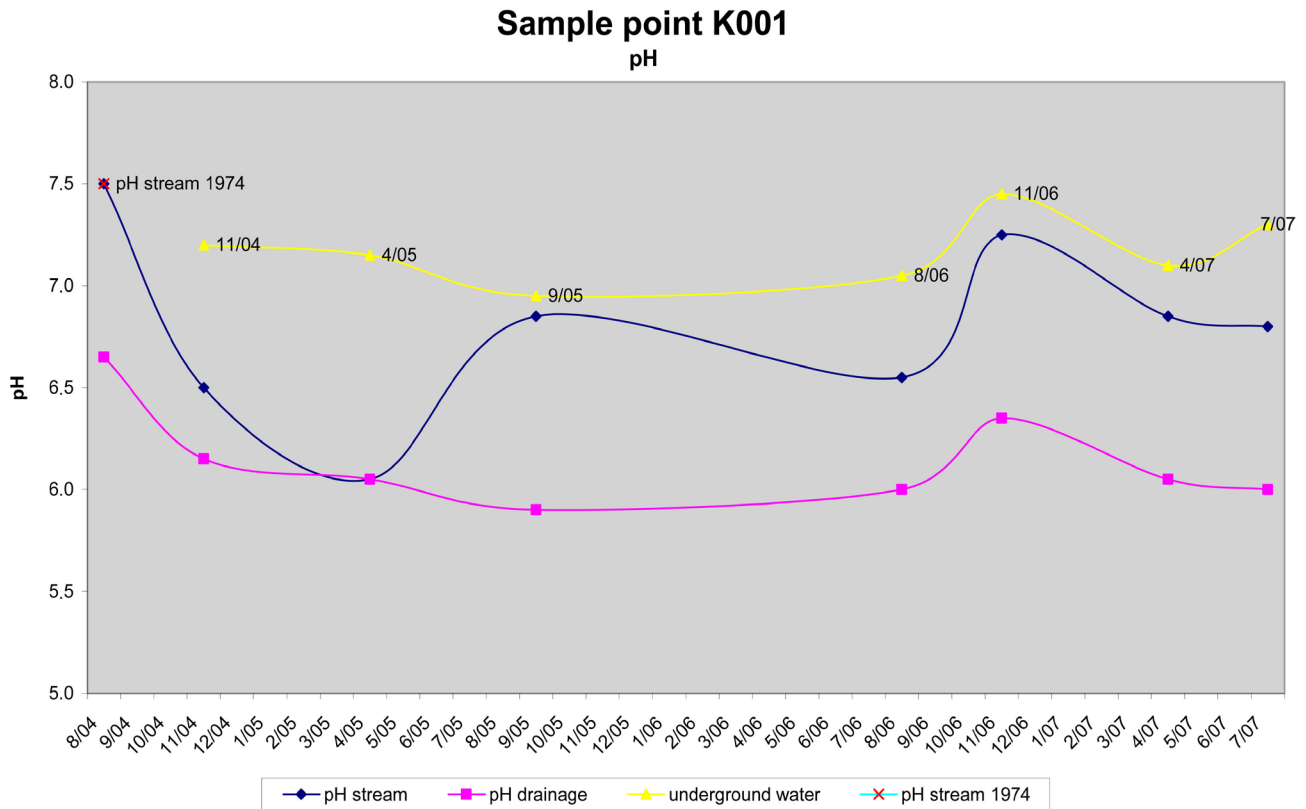


Figure 2. Development of pH values in the extensively used Železná area.

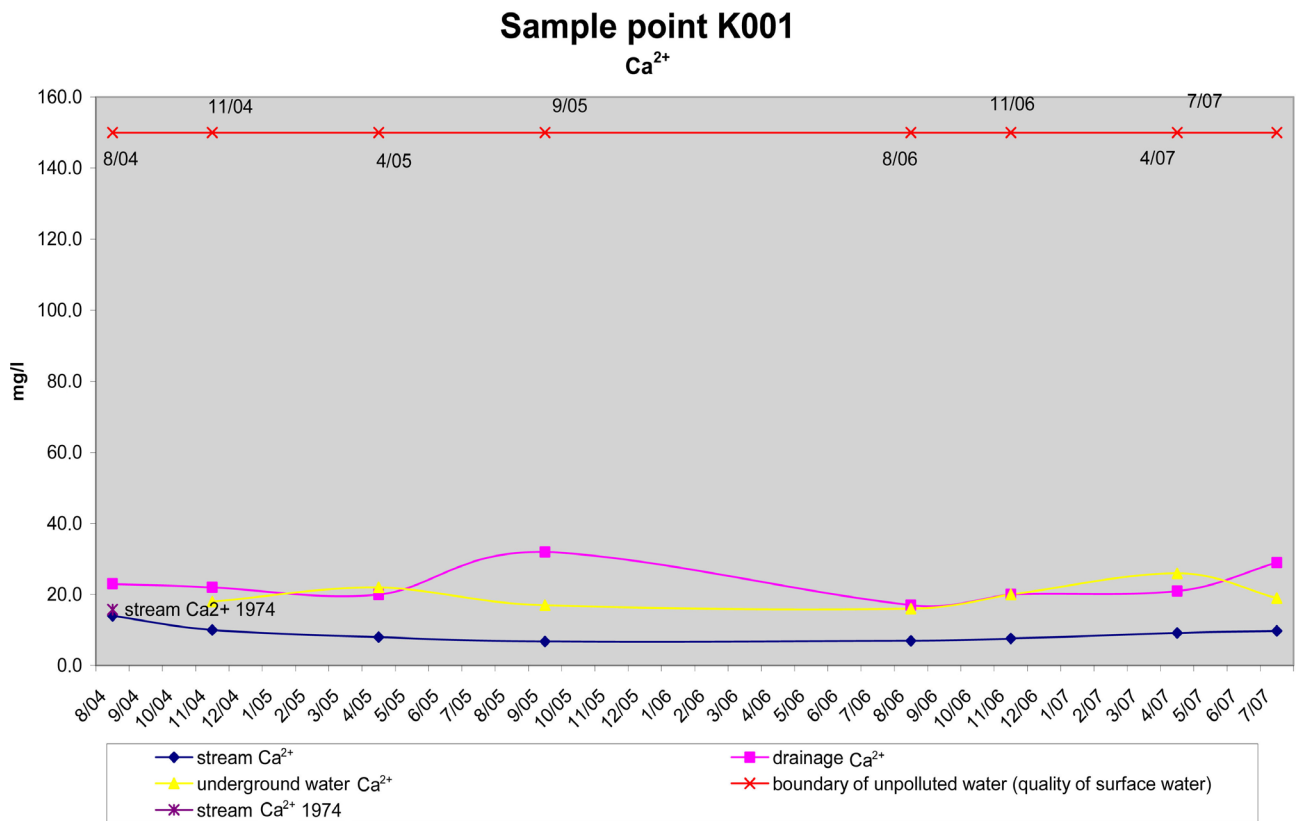


Figure 3. Development of Ca²⁺ content values in the extensively used Železná area.

concentration of Ca^{2+} and to a certain extent Mg^{2+} ions. This trend in the changes in bicarbonate concentration was, as expected, closely connected to the pH values. The increasing concentration of sulphates and chlorides (from a concentration of 7 mg up to 12 mg Cl^-/l) correlated positively with the decrease in pH values and the increase in acidity. The concentration of potassium ions in all the stream waters was relatively low in all the periodically collected samples (2 to 5 mg K^+/l). Similarly, the nitrite content was very low (on average 0.03 mg NO_2^-/l). Likewise, the concentration of nitrates is very low in the watercourse (on average 5 mg NO_3^-/l), and is therefore below the limit value for unpolluted water (the highest permitted concentration for unpolluted water is 3 mg $\text{N-NO}_3^-/\text{l}$, which converts to approximately 12 mg NO_3^-/l). The phosphate content in the stream water also does not exceed the boundary value of PO_4^{3-} concentration for unpolluted water set at 0.05 mg $\text{P-PO}_4^{3-}/\text{l}$, which converts to approximately 0.15 mg $\text{PO}_4^{3-}/\text{l}$. The differences over time in the concentration of phosphates are, all in all, negligible. The ammonium ion content also does not reach the threshold value set for unpolluted water (Figure 4). The stream water at sample point no.1 is therefore definitely unpolluted.

drainage water

Unlike stream water, the systematic monitoring of drainage water did not begin until the start of the “current” samples, beginning with sample no.2 collected in August 2004. The analytical data for drainage water differs considerably from that for surface water: its pH has a lower value (Figure 2), which is connected with the increase in acidity; at the same time, alkalinity has hardly decreased at all and remains relatively high (1 - 1.5 mmol/l). Likewise, overall hardness has

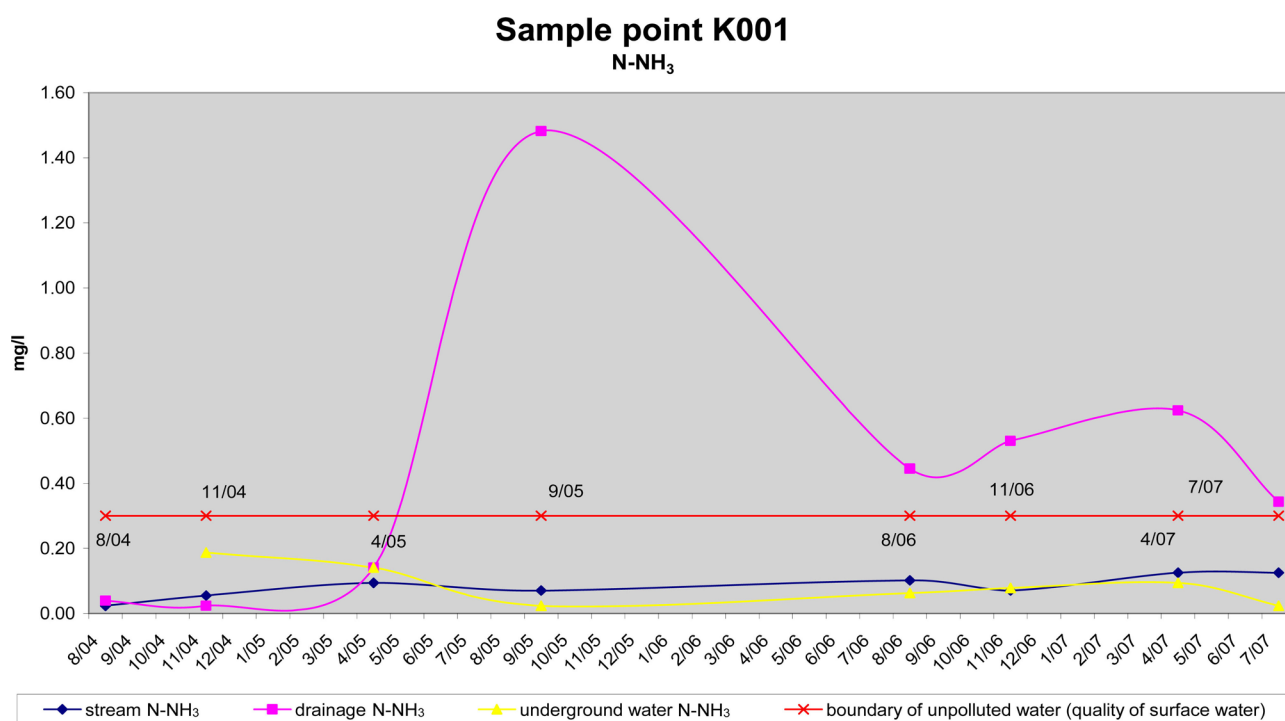


Figure 4. Development of N-NH₃ values in the extensively used Železná area.

increased considerably (especially in the more recent samples) in correlation with the increase in the concentration of magnesium and calcium ions (**Figure 3**). However, not even these increased values reach the critical level for assigning this water to the “slightly polluted” category. The same applies to electrical conductivity values. Even the highest measured value (333 $\mu\text{S}/\text{cm}$) does not exceed the limit value for slight pollution (40 mS/m), although it has, on average, three times the electrical conductivity value measured in the nearest watercourse [1]. In connection with the increase in alkalinity, there was an increase in bicarbonate content (within the range of 60 - 100 $\text{mg HCO}_3^-/\text{l}$). However, the concentration of sulphates in the drainage water has not increased much in comparison with those in the stream water. Similarly, chloride content (on average approximately 10 mg/l) decreased at first, then, in the later samples, it gradually increased. In neither of these cases, however, were the concentrations great enough to confirm the pollution of the drainage water, nor did the concentration of K^+ ions in the drainage water differ much from the content in the surface water. It fluctuated inconclusively between 2 and 4 $\text{mg K}^+/\text{l}$. According to the phosphate concentration, the drainage water quality falls into category II. (“slightly polluted”).

Sample Point K 002

stream water

At Sample Point K 002 (Železný A stream), we found, with the exception of the initial (historical) value (pH 6.5), a similar development of pH values over time as in the previous case (K 001), although the absolute pH values at K 002 are all lower than at sample point K 001. Likewise, the trends in acidity-alkalinity show a similar pattern. The concentrations of magnesium and calcium ions also display similar values and development. The overall hardness values, and their development over time, were very similar for the stream water at both points. Only the electrical conductivity - E.C. values (**Figure 5**) were somewhat lower compared with the E.C. values in the water of the Nivní stream. The bicarbonate concentration fluctuates between 25 mg and 40 $\text{mg HCO}_3^-/\text{l}$ and alkalinity fluctuates between 0.4 and 0.7 mmol/l . Their development is proportional to the changes over time in the pH values. The concentration of chlorides (**Figure 6**), nitrates (**Figure 7**), sulphates (**Figure 8**), and nitrites did not exceed the boundary value for slight chemical pollution of stream water. According to the phosphate concentration (**Figure 9**), in August 2006 and April 2007, the stream water falls into the category of very heavily polluted. In the preceding samples, and the subsequent one collected in July 2007, the phosphate concentration in the stream water was, however, below the level of slight pollution. With the exception of the period with a higher phosphate concentration, the water is unpolluted.

drainage water

The drainage water collected at Sample Point K 002 (near the Železný stream) displays relatively high values in nearly all its chemical characteristics—the

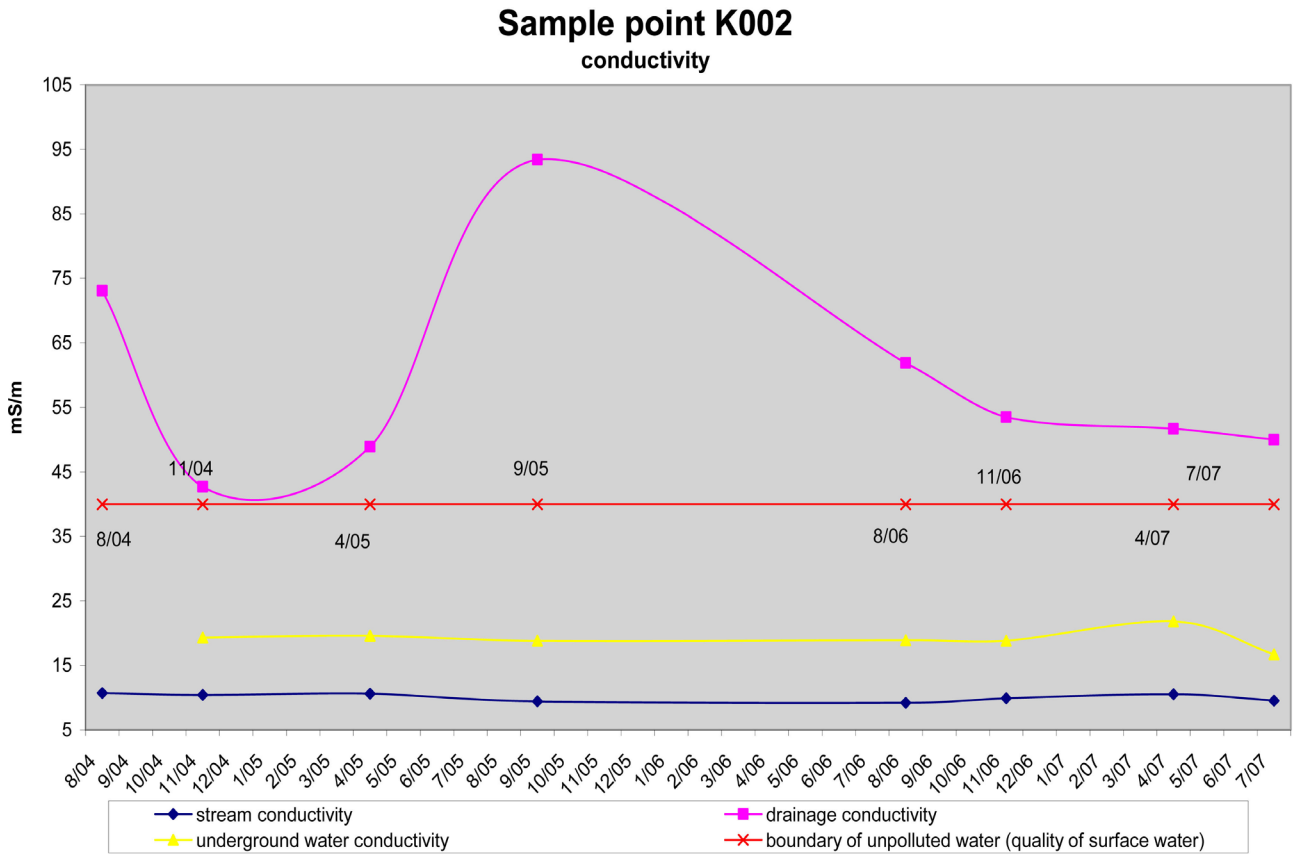


Figure 5. Development of conductivity in the extensively used Železná area.

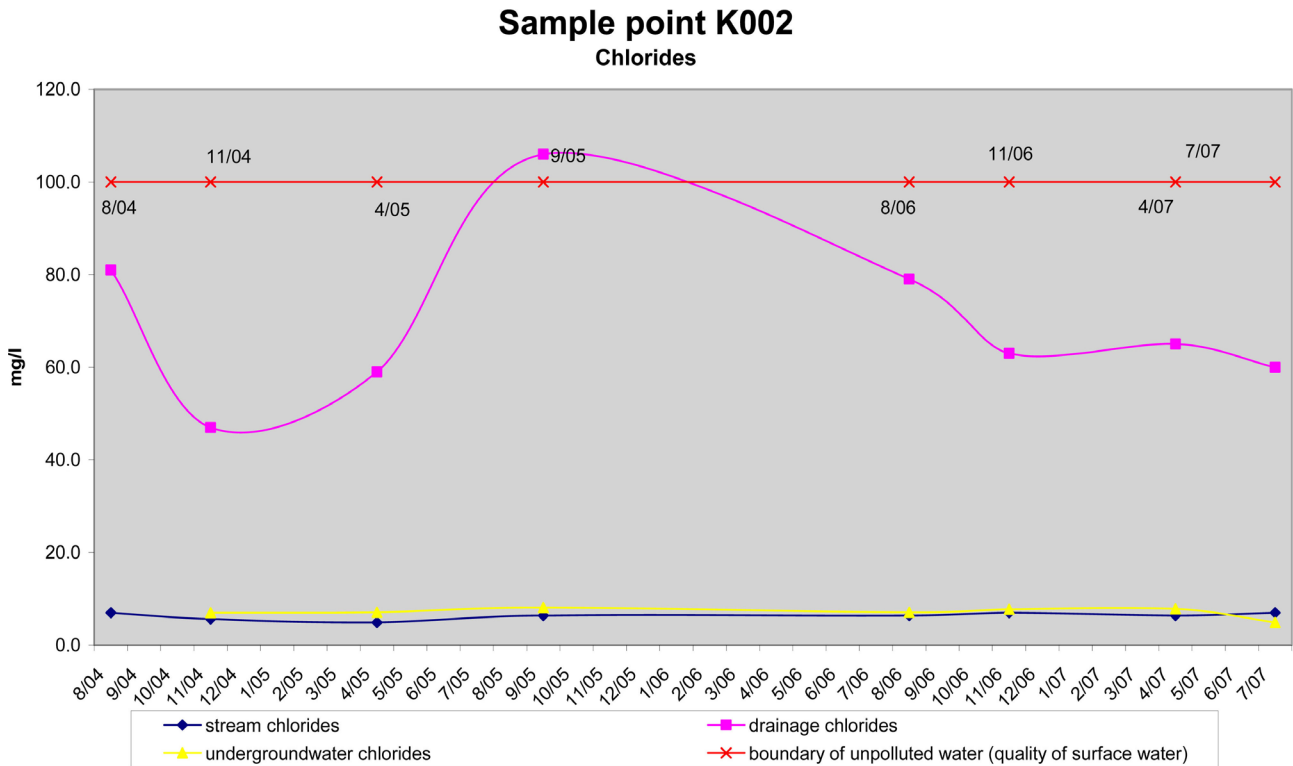


Figure 6. Development of chloride content in the extensively used Železná area.

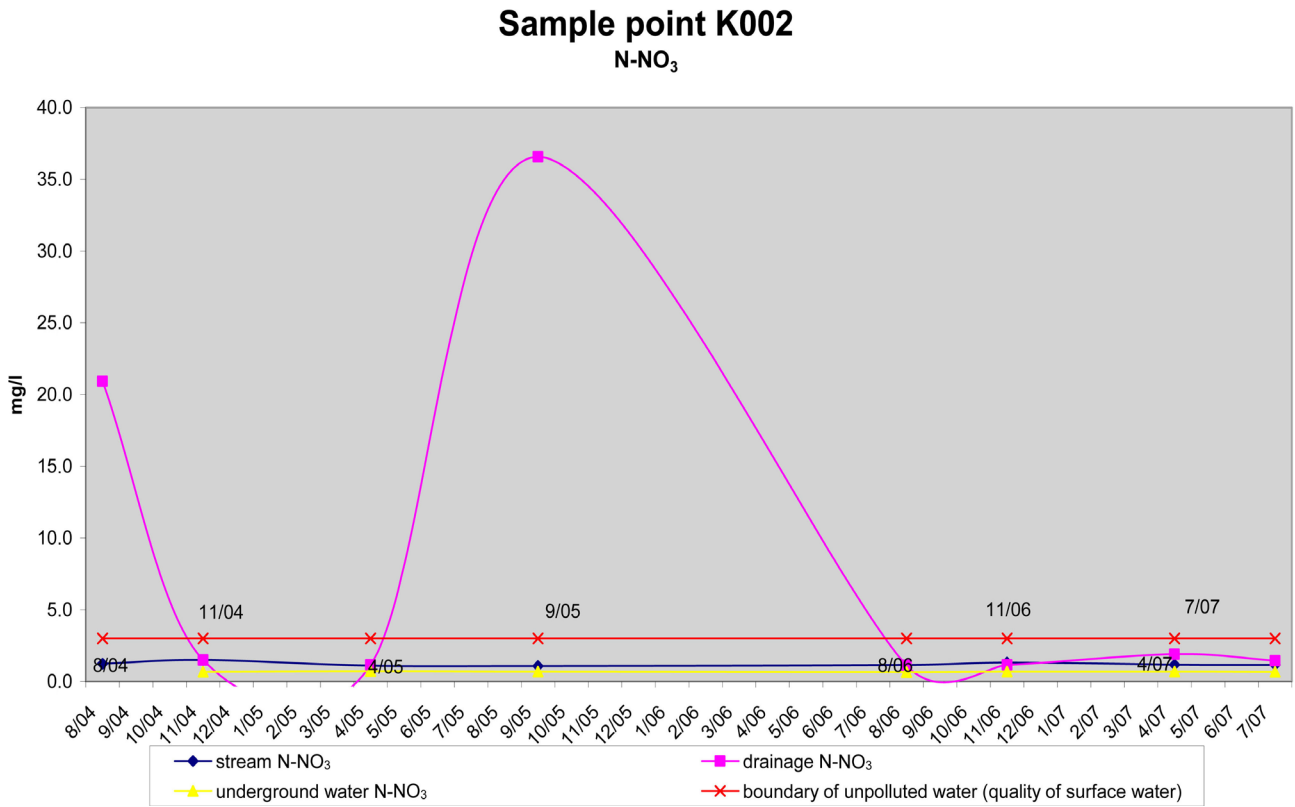


Figure 7. Development of N-NO₃ content in the extensively used Železná area.

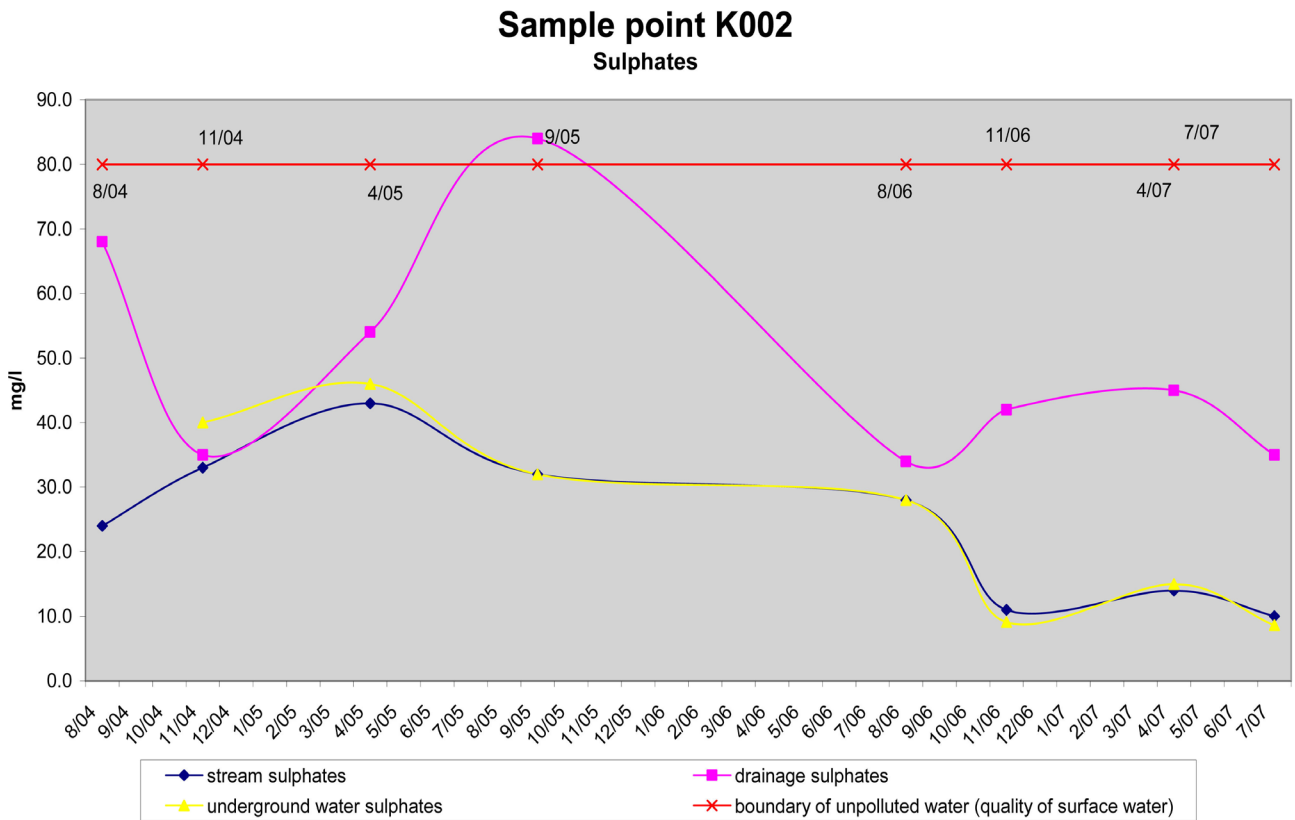


Figure 8. Development of sulphate content in the extensively used Železná area.

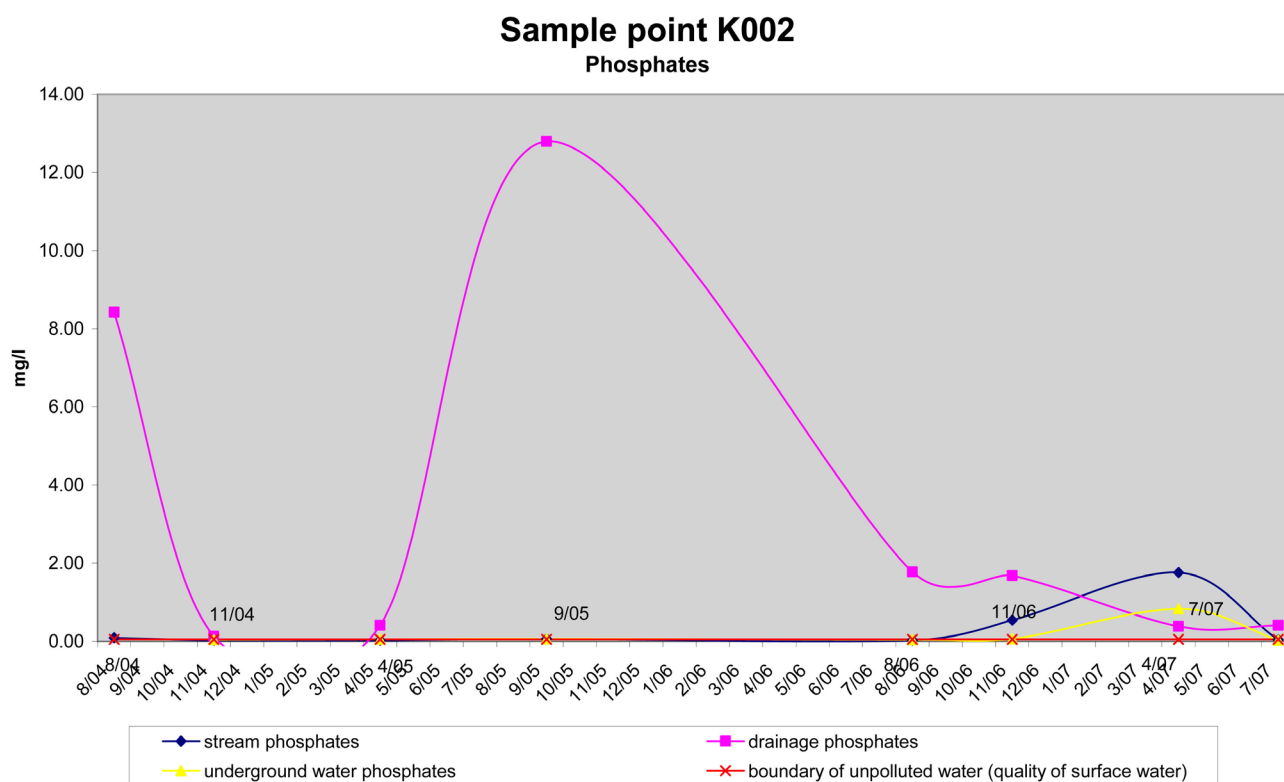


Figure 9. Development of phosphate content in the extensively used Železná area.

highest of all six sampled drainage waters: Its alkalinity (1.85 mmol/l) is higher than that of all the other drainage and stream waters. Its average bicarbonate concentration (approx. 105 mg HCO_3^- /l) is also higher than the average values at the other sample points, as are its extremely high overall hardness values (exceeding 10 German degrees). However, due to the absence of relevant qualitative norms, we cannot, on the basis of these results, determine its pollution category. Of course, although the norm does not explicitly set threshold values for overall hardness, with such high values it is almost certain that chemical pollution has in fact reached at least category II., but more likely category III. As in the case of potassium where, similarly, no level of pollution has yet been categorized by a relevant norm, we have good reason to believe that a concentration approaching 40 mg K^+ /l is evidence of at least a medium level of pollution. The concentration of ammonia ions in April 2004 exceeded 0.7 mg NH_4^+ /l, which means that according to norm [1], the quality of that drainage water shows a medium pollution level. However, in the sample collected in August 2006, an extreme ammonia content value was recorded, far higher than in the other samples—6.59 mg NH_4^+ /l—suggesting that this drainage water is very heavily polluted. Regarding sulphate content, however, (Figure 8), pollution is only “slight”, whereas pollution from phosphates (Figure 9) would, according to the limit values of the same norm, mostly fall within the medium category. Although, as early as the first sample of drainage water which was collected at the second sample point in August 2004, a value of over 8 mg PO_4^{3-} /l was found (that is approximately 2.6 mg

P-PO₄³⁻), and in September 2005, an extreme concentration values of 12.79 mg PO₄³⁻ was measured, which approximately corresponds to 4.3 mg P-PO₄³⁻, a value exceeding the lower limit of the highest level of contamination—very heavily polluted water. The nitrate concentration (Figure 7) reaches very undesirable values in the drainage water, especially in the second and fifth samples (159 mg NO₃⁻/l, which converts to more than 35 N-NO₃⁻/l), which, according to the norm referred to above, automatically assigns the water to the category of very heavily polluted water. This is borne out by the very high content of nitrites (0.20 mg to 0.37 mg NO₂⁻/l), although we so far lack a threshold figure for the nitrite pollution of surface and drainage water.

Sample Point K 003

stream water

At Sample Point K 003, we once again collected samples of stream water (from the Železný B stream) and of the nearest drainage water. The development over time of pH values is as follows: In the oldest “historical” sample, the water showed a neutral reaction (pH 7.0). Thirty years later, its pH value was even higher (7.45) with a subsequent decrease to pH 6.0 and then a return to a neutral to slightly alkaline reaction. The development of pH values is very similar to the changes of alkalinity and bicarbonate content over time. This marked variability in pH values can be explained by the low level of salinity, a very low content of soluble salts and, consequently, the low buffering of this relatively very clean water. This is also borne out by low values of electrical conductivity, a low level of monitored bivalent cations, with the exception of the second sample (from August 2004), and, likewise, an increase in the overall hardness values in those stream water samples (an increase of 4.8 German degrees with a decrease in the subsequent samples to 1 German degree). In the second sample, we also found raised sulphate, nitrate and phosphate values, although they hardly reach the limit value which divides unpolluted water from slightly polluted water. The concentration of ammonia ions does not alter that fact either.

drainage water

The chemical characteristics of the drainage water from the vicinity of the Železný B stream (sample point K 003) do not attain values which exceed the threshold pollution values, or which would assign the water to a lower quality category. The pH values are, admittedly, all within the region of a slightly acidic reaction, but their deviations from a neutral reaction are, on the whole, small. Alkalinity fluctuates around the value of 0.7 mmol/l, while the average bicarbonate content was 40 mg HCO₃⁻/l. The developmental trend of acidity is inversely related to the development of pH values, and the acidity values are very low. Overall hardness is also very low, and declined from the second sample (August 2004) to the fifth sample. The values of the concentrations of monitored cations and anions are also very low, and it follows logically that the values of electrical conductivity are also low (on average only 110 mS/m), thus, the chemical pollution threshold values were not exceeded.

Sample Points K 004 and K 005

stream water

The next two sample points for surface water are K 004 (Farský A stream) and K 005 (Farský B stream). We discovered that the development over time of pH values at both points is very similar, and some of the values are identical. The same applies to the values and development of alkalinity. Titration acidity is very low. The development of overall hardness values at both sample points shows a downward trend. The distribution of values of the concentration of monitored cations corresponds to the distributions of values for both previously evaluated watercourses, with the exception of one case (in November 2006) when the concentration of ammonia ions in the water of the Farský B stream reached the threshold concentration for slightly polluted water, of 0.30 mg/l. Likewise, the values of the monitored anions (bicarbonates, chlorides, phosphates, nitrates and nitrites) are, for virtually the entirety of the monitoring period, within the limits for chemically unpolluted surface water.

drainage water

The closest water (Sample Points K 004 and K 005) has very similar values for a number of chemical indicators: in the case of pH values, there was a distinct difference only in the fifth sample, in which the pH value declined to 5.6, while its paired value remained at 6.35. The results of the acidity-alkalinity specification were clearly linked to the pH values. The highest alkalinity values did not exceed 0.85 mmol/l, while acidity did not fall below 0.55 mmol/l. As with the water from the Farský stream, neither of the two drainage water samples displayed any extreme values in any of the monitored chemical indicators. That applies to the concentrations of cations (including ammonia ions), as well the concentration of anions (including bicarbonates), overall hardness, and the water's electrical conductivity.

In conclusion, we can state that most of the monitored drainage water in the Železná area, even when the flow is weak, conforms to the quality norm's definition of unpolluted or only slightly polluted surface water. The single, unwelcome exception to the rule is Sample Point K 002—the drainage and partly stream water in the vicinity of the Železný stream—where serious pollution has certainly occurred, as is shown by the values of several chemical indicators (nitrates, phosphates, ammonia ions). The cause of the pollution is very probably the manure heap in the study area, which was located about 300 m from the sample point. The other drainage water in the extensively exploited soils of the Železná study area conforms, without exception, to the relatively strict criteria for surface water evaluation.

Sample Point K 006

This concluding observation refers to the chemical characteristics of groundwater or well water (Sample Point K 006): The values of the chemical indicators measured here differ markedly from the stream and drainage water values. During the monitoring process, we found relatively high levels of alkalinity (up to

1.9 mmol/l) and relatively high overall hardness (up to 5.8 German degrees), which is reflected by the relatively high concentration of bivalent cations—up to 25 mg Ca²⁺/l (Figure 4)—of 12 mg Mg²⁺/l. Their values in the well water are lower than in the drainage water, although in some samples they slightly exceed the concentrations in the stream water. In no case, however, do they exceed the threshold values for polluted water. The nitrate concentration (on average 5 mg/l) is within the range defined for unpolluted water (Figure 7). Likewise, nitrites, for which we still have no norm setting concentration limits, are at a very low level (0.03 mg NO₂⁻/l). The concentration of ammonia ions at 0.2 mg/l does not indicate that the water is chemically polluted. Throughout the whole monitoring period, the phosphate content (Figure 9) never exceeded the upper limit for water unpolluted by phosphates, although in the last two samples, especially in April 2007, it attains a surprisingly high phosphate concentration of 0.80 mg PO₄³⁻/l, *i.e.* approximately 0.40 mg P/l. That would correspond at least to a medium level of phosphate pollution. It is difficult to find a satisfactory explanation for this deviation in the phosphate concentration: It appears that erosion has occurred, or the original manure heap has been washed away. From our monitoring of the development, or increase in the phosphate concentration in the drainage and stream water during the course of our monitoring, it is apparent that the increase in their concentration has affected both the drainage and the stream water at the individual sample points, but not at the same time, and with varying intensity. At Sample Point K 002, the increase was most intensive as early as April 2005, while at Points K 003 and K 004, the phosphate concentration did not culminate until 2006. At Sample Point K 005, the increase in concentration was not too high and developed more gradually, but it lasted for a relatively long time, from as early as spring 2005 until November 2006, and not until later (April 2007) did phosphate pollution also affect groundwater.

3.2. The Chemical Characteristics of Drainage Water in the Haklový Dvory Study Area

We present, as supplementary information, the characteristics of four drainage water samples (Table 3) collected on the 27th of April 2005 at Žabovřesky and at three other sites in Branišov (17 May 2005).

A survey of the analyses of these four drainage water samples shows that in

Table 3. The chemical characteristics of drainage water collected in the Žabovřesky and Branišov areas.

locality	pH	acidity	Cl ⁻	K ⁺	NO ₃ ⁻	NO ₂ ⁻	Ca ²⁺	SO ₄ ²⁻	Total hard.	E.C.	SO ₄ ²⁻	PO ₄ ³⁻
Žabovřesky	6.6	0.45	52	20	123	0.06	66	86	9.3	700	0.13	0.27
Branišov 1	6.8	0.15	43	17	149	0.36	62	79	15.1	684	0.34	0.10
Branišov 2	6.6	0.15	71	4	109	0.02	76	100	20.3	708	0.10	0.16
Branišov 3	6.8	0.15	42	9	74	0.67	82	96	22.7	711	0.67	0.91

some of the chemical characteristics, the water varies relatively little, while in the case of other characteristics, the distribution of values is surprisingly marked. For example, in the pH values (in all cases the water is only slightly acidic), the differences are hardly conclusive. The same applies to electrical conductivity (with the exception of the sample from Žabovřesky) and to the acidity of the analyzed drainage water. There was also a relatively high degree of concurrence among the ascertained concentration values of calcium, chlorides and nitrates. By contrast, the greatest variation in analytical data is found in the potassium ion concentrations and in the nitrite, ammoniac nitrogen and phosphate content. If we compare the values ascertained for the various indicators with the threshold values of the quality categories for purity or surface water pollution, we discover that, according to certain criteria, the water is relatively clean and of good quality, while according to other criteria it is polluted or even very heavily polluted. For example, based on the concentration of chlorides, sulphates or ammonia ions, the water would be categorized as unpolluted or only slightly polluted (Branišov 3). The water from the Žabovřesky area falls within quality class II. By contrast, the very high concentration of nitrates is almost startling. The content in the all the collected samples significantly exceeds the lower threshold value for very heavily polluted (pollution category 5), *i.e.* 13 mg N-NO₃⁻/l, which converts to 57 mg NO₃⁻/litre. According to the threshold values for phosphate concentration, the water from the Žabovřesky area falls within pollution category II., *i.e.* slightly polluted. The samples from Branišov I. and II. would even correspond to category I., while the third sample from Branišov, because of its concentration of 0.91 mg PO₄³⁻, *i.e.* 0.30 mg P-PO₄³⁻/l, falls within category III.—moderately serious phosphate pollution. Likewise, a comparison of the threshold values for electrical conductivity with the values found in the drainage water shows that the water falls within categories II. and III. (slightly polluted to medium polluted).

Our interpretation of these facts is that the intensive management of these land areas, regular ploughing, the use of organic and mineral fertilizers and liming (although not very intensive in the last decade) have probably caused part of the soil's nutrients to be released in their mobile form accessible to plants, and that erosive washing out and loss of sorptive phosphates may also have occurred in the dispersed soil particles, as well as the washing out of nitrates and nitrites and the loss of salts and organic soil material, which causes the contamination of drainage water. At the same time, however, it should be noted that the relatively high concentration of some of the afore-mentioned chemical contaminants is not caused by the rate of flow of the drainage water, as was the case with the drainage water in the Železná study area, but by the direct impact of land management in the Haklovy Dvory area.

4. Conclusions

Monitoring of the quality of drainage water and a comparison of its quality with

that of surface water, as well as a comparison of the changes in the quality of drainage water from areas where the soil is used extensively (meadows, pastures, permanent grass growth - Železná area) with the quality in areas where the soil is used intensively (arable land-Haklovy Dvory area) was carried out within the framework of research into the changes in the characteristics of drained and long-term irrigated soils, and their impact on soil and water conservation.

In the area where pastoral agriculture is carried out, with very few exceptions, no pronounced chemical pollution of the drainage water was found, despite the fact that the drainage water flow was relatively low. By contrast, in the area with intensive agricultural activity, the concentrations of chemical characteristics in some samples of drainage water were relatively high, in some cases high enough to place the water in the heavily or very heavily polluted quality categories, despite the relatively strong flow. We can therefore conclude that the pollution of drainage water is directly connected to the type of farming carried out on the drained soil.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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