17. SUMMARY

Aims of this research were to find factors of catchments which cause high concentrations of nitrate in surface water and high difference between their summer minima and winter maxima and to try to say what is necessary to improve in the catchments.

In the 90's there were monitored concentrations of nitrate in small streams of the Švihov drinking water reservoir basin on the Želivka River in the Bohemo-Moravian Highland by the Agricultural Water Management Authority. 36 profiles were analysed. Frequency of extractions was once per month. Analysed period was from June 1993 to June 2002. Unfortunately, not all the profiles were monitored all the time (according to amount of money for research). All the catchments are made of weathered acid crystalline rocks.

Although amount of fertilizers rapidly decreased in the 90's in Czech agriculture concentrations of nitrate somewhere increased. There must be other important factors. 9 factors were researched in every catchment: C_{90} (concentration which will not be exceeded with probability 90% - from measured data), amplitude of average month concentrations per year for all the period of monitoring, total area of the catchment, portion of arable land, portion of water areas, portion of infiltration areas covered by arable land (infiltration areas were delimited according to valuated soil-ecological units data - all the characteristics of soil were taken into account), portion of artificially drained areas, number of inhabitants, number of livestock units. These 9 factors were taken into the Factor Analysis. **The Factor Analysis showed that the height of maximal values of nitrate concentrations in the end of winter and also the height of differences between summer minimums and winter maximums are influenced especially by the portion of arable land in the catchment, by the portion of infiltration areas covered by arable land and by the portion of artificially drained areas. On the contrary, water areas have the positive effect.**

In 1955 extractions from some of the same profiles were taken. Therefore these data are valuable for the comparison. Although in the 1955 there lived more people and farm animals in the catchments the concentrations of nitrate were far lower than in the 90's. We can ask what has changed in the catchments so much. The main change in the landscape was the construction of artificial subsurface drainage from the 60's to the 80's. The subdrainage induced a change of redox conditions and it accelerated runoff from the catchments. Before waterlogged grasslands in riparian zones with good conditions for denitrification often were changed into arable land.

These 36 profiles monitored by the Agricultural Water Management Authority (AWMA) together with 9 profiles monitored by the Povodí Vltavy, s. p., (which monitors bigger brooks in the Želivka River basin than AWMA – therefore those catchments are larger) were included into the Multiple Regression Analysis. The most significant factors influencing the nitrate contamination of the streams were both portion of arable land in the catchment and portion of water areas in the catchment. (Higher portion of arable land leads to higher nitrate concentrations and higher portion of water areas leads to lower nitrate concentrations.)

Influence of artificial drainage on both water and nutrient regime

There is a positive effect of artificial drainage for increasing of the agricultural production because the physiological depth of soil and capacity of soil for processes feeding crops are increased. But after artificial decrease of water table a quick mineralization of organic matter in the soil begins and products of this mineralization leach out into drainage water especially in the nitrate form. Maximum of this leaching is from the 2^{nd} till the 4^{th} year after artificial drainage (NOVÁK, 1994; ZLATUŠKOVÁ et NOVÁK, 2000).

PAČES (unpublished research report from monitoring lasting 1976–1999 by the Czech Geological Survey) described similar behavior of nitrate concentration after artificial drainage in a small experimental catchment Vočadlo (59 ha) in the Želivka River basin. Before artificial drainage in the year 1982 minimal values of nitrate concentrations were about 4,5 mg $N\text{-}NO_3^-.l^{-1}$ (20 mg $NO_3^-.l^{-1}$) (period 1976-1981). But in the years 1983-1987 maximal values achieved to 21,5 mg $N\text{-}NO_3^-.l^{-1}$ (95 mg $NO_3^-.l^{-1}$). In the period with low values there were appeared samples of water with maximal nitrate concentrations about 11,3 mg $N\text{-}NO_3^-.l^{-1}$ (50 mg $NO_3^-.l^{-1}$). In the period with high values there were appeared samples of water with minimal nitrate concentrations about 15,8 mg $N\text{-}NO_3^-.l^{-1}$ (70 mg $NO_3^-.l^{-1}$). In the years 1987-1990 nitrate concentrations decreased again and after 1990 till the end of monitoring in 1999 they oscillated round 14,7 mg $N\text{-}NO_3^-.l^{-1}$ (65 mg $NO_3^-.l^{-1}$). After the artificial drainage a part of originally wet grasslands in the upper part of the valley was ploughed. This fact more increased the nitrate leaching from the soil. The profile is situated after 30 meters of the drainage issue and there is no other source of water above the profile except the drainage. Therefore those samples are drainage water.

A neglected fact of the mineralization of organic matter in the soil after the artificial drainage is acidification of soil and water. During the oxidation of the organic matter many protons are released and the pH is decreasing (PITTER, 1999). Also production of CO_2 (greenhouse gas) owing to mineralization of soil carbon after drainage is enormous. NOVÁK

(2004) writes that after artificial drainage within 8–10 years until new balance was consolidated 2,2 tons of NO_3^- ion per every drained hectare of soil leached out into the hydrosphere and 113 tons of CO_2 per every drained hectare of soil escaped into the atmosphere. These numbers are huge and warning.

But the problem probably is not only in quick mineralization of organic matter in soil after the artificial drainage. It is visible in the PAČES report from the small experimental Vočadlo catchment. New stable nitrate concentration 65 mg $NO_3^-.l^{-1}$ after the year 1990 is much higher than before the drainage. KVÍTEK et LEXA et al. (2005) described another possible long-term effect of artificial drainage. Artificial drainage of the wet alluvial areas which were used as meadows and pastures enabled the use of heavy agricultural mechanization and these areas were ploughed in many cases. With the drainage the redox conditions in the soil were changed and anoxic places were aerated. Traditionally in the Bohemo-Moravian Highland there were tilled upper parts of the catchments where soil was thin and sandy. Those parts are infiltration areas of the catchments. Original alluvial grasslands were probably watered by springs with high amount of nitrate. Nitrate could be reduced in anoxic conditions by denitrification or fed by the grass cover. But owing to the artificial drainage of those riparian zones in the depth 1 meter by tubes nitrate has no place where it could be eliminated and it comes into the following rivers. Building up of artificial drainage seriously damaged ecological stability of the landscape (drainage accelerates runoff of water of course too). The key role of the riparian zones is shown also by SCHIPPER et COOPER et DYCK (1991).

SOUKUP et PILNÁ (2003) also showed from 13 years lasting monitoring that drainage water contains 4–5 times more nitrate than surface water. Average monthly nitrate concentrations from all the period of monitoring there were from 10,8 mg $N\text{-}NO_3^-.l^{-1}$ (48 mg $NO_3^-.l^{-1}$) in October up to 19,2 mg $N\text{-}NO_3^-.l^{-1}$ (85 mg $NO_3^-.l^{-1}$) in February and March.

Ecological stability is defined as a resistance of the landscape towards disruption and recuperation of the landscape. By the construction of artificial subsurface drainage the system has got a new level of metastability in the model of "Russian hills" which was described by GODRON & FORMAN (1983).

I tried to perform an analysis of all the Želivka River basin in the all postwar period. Average annual nitrate concentration and nitrate loss in the inflow of the Švihov drinking water reservoir (or in the Želivka River closing profile before the construction of the Švihov dam) and many relevant characteristics of the total Želivka River basin (annual precipitation, annual average flow rate, land use, portion of artificially drained area in the basin, mineral nitrogen fertilization, amounts of diverse farm animals, portion of inhabitants with sewerage in the basin, portion of inhabitants with cleaning their sewerage in the waste water treatment plant in the basin, total areas under diverse crops, and yields of these divers crops) were included into this analysis. I tried to find all these characteristics out for every year from the period 1945–2003 but, unfortunately, I was not successful at some of them. Results of the analysis showed that the highest Pearson correlation coefficient between the nitrate concentrations and the other characteristics was at portion od artificially drained area in the basin (0,94). At portion of permanent grasslands the Pearson correlation coefficient was –0,86 and at mineral nitrogen fertilization 0,79. With increasing yields of all the crops (which reflect amount of fertilization), with decreasing areas under crops which are unpretentious for nutrients (rye and oat), and with increasing areas under more fertilized crops (barley, maize, colza) the nitrate concentrations in strams increased, how it was shown in high correlation coefficients. Correlation coefficient between nitrate concentrations and portion of inhabitants with sewerage in the basin was also high (0,87). Correlation coefficients between nitrate loss and other factors are lower, but at the portion of artificially drained area in the basin the correlation coefficient is the highest from them again (0,74).

For improvement it would be necessary to grass over infiltration areas of the catchment. Cultivation of winter crops would bring a partial improvement because the highest leaching of nitrate from soil to water is in the end of winter from bare soil with no vegetation.

Another solution would be to build and keep small ponds and wetlands where nitrate could be eliminated in anoxic conditions by denitrification. It is visible in the AWMA profile 304-46 (the Blatnice Stream). Although 19,6% total area of its catchment has been artificially drained, the closing profile 304-46 was the cleanest profile from all here analysed profiles in the Želivka River basin as concerns nitrate contamination (C_{90} = 2,2 mg $N\text{-}NO_3^{-}.l^{-1}$) and it differed from all other profiles much. The reason of this positive fact is in the high portion of water areas in the catchment (2,6% - the highest portion from all here analysed profiles.

Building up of artificial drainage from the 60's to the 80's was a serious damage for Czech landscape. About 25% of Czech agricultural soils are artificially drained (NOVÁK, 2004).