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WATER QUALITY CHANGES IN THE ELBE RIVER BASIN

J. Langhammer: *Water Quality changes in the Elbe River Basin.* – Geografie Sborník ČGS, 109, 2, pp. 93–104 (2004). – In the course of the 90s, the Czech part of the Elbe river basin underwent a significant change in the quality of surface water. After a long period of intensified pollution hitting the peak at the end of the 80s, reduced amount of emissions from main industrial and municipal sources led to a lower pollution load of the Elbe and its principal tributaries. The scope and speed of such water quality changes is unprecedented in the Czech as well as in the European perspective. Decrease in the pollution level is however spatially limited to the Elbe river and its main tributaries. Further reduction of emission load will not result in corresponding decline of water pollution. This is due to different evolution of rivers of different sizes, but mainly to insufficient decrease of pollution load in the headstream areas of the river basin. It is this area of small watercourses that has to be in the centre of attention because without its radical changes it isn't possible to ensure permanent improvement of water quality in the Elbe and its tributaries.
KEY WORDS: Hydrology – water quality – pollution – modelling – Elbe.

1. Introduction

Changes in water quality occurring in the 90s in the Czech part of the Elbe and in a large area of its river basin belong among the most significant environmental changes not only in the national, but also in European context. Focused efforts caused by international pressure and changes in political situation at the turn of the 90s resulted in projects aiming at remediation of main sources of industrial and municipal pollution of the Elbe and its main tributaries. These actions were responded by fast and significant decrease in the Elbe pollution load as indicated by most of monitored parameters, and by overall improvement of its environmental state.

However, changes in water quality of the Elbe river basin have been spatially quite differentiated. This paper looks at the internal structure of the process and different dynamics of water quality changes in watercourses with different size of structure and geographical position. Assessment is focused on main load indicators of organic substances and nutrients. Mathematic models help simulate variable scenarios of further Elbe water quality development based on the expected emission load of the river basin.

2. Material and Methods

2. 1. Methodology

Analytical assessment is based on two main methodological procedures – standard geostatistical assessment and applied mathematic modelling.

Geostatistical assessment was employed to analyse developments of surface water quality in the hydrographical network of the Czech part of the Elbe river basin, to analyse pollutant emissions in the aquatic environment, and spatial relations using the geographic information systems (GIS).

Analyses of the Elbe river basin emission load was supported by a database of recorded sources of sewage emissions of the State Water Management Balance (the SVHB). To perform spatial analysis using GIS the digital Water Management Map and the data from the CORINE landcover geodatabase were used.

Assessment of the Elbe quality state and development of its individual aspects was based on data provided by monitoring of surface water quality in profiles of the state network administered by the Czech Hydrometeorological Institute (CHMI). We selected 141 profiles for the analyses, representing individual river basins in terms of geographical location, physical and geographic conditions, social and economic use and river basin structure size, water volume and prevailing character of pollution sources. Assessment was based on the time period 1990–1999 and covered parameters of BOD-5, COD, $N\text{-}NH_4$, $N\text{-}NO_3$ and total phosphorus.

2. 2. Study area

The Elbe river basin covering over 50 000 km^2 concentrates pollution load almost from whole Bohemia showing high concentration of population, industry and agriculture. The Elbe itself is marked by many significant direct pollution sources because favourable geographical conditions in the past led to long-term natural concentration of inhabitants, intensive agricultural production and establishment of many industrial plants since the mid of the 19th century (Fig. 1).

In the course of the first and mainly the second half of the 20th century, the Elbe as well as other big rivers in Europe showed a dramatic rise in pollution according to all monitored indicators due to high concentration of anthropogenic activities. The peak load was reported in the 70s and 80s and most of big rivers in Western Europe underwent a similar process. They, however, were exposed to significant changes from the end of the 60s aimed at stopping further contamination and return to original natural structure. In case of the Elbe, problems stayed unresolved for many years and in the 70s and 80s when European rivers like Rhine, Saale, Mosel etc. showed significant decrease in pollution and new rehabilitation of natural ecosystems, the Czech Republic suffered the highest historical pollution load of rivers.

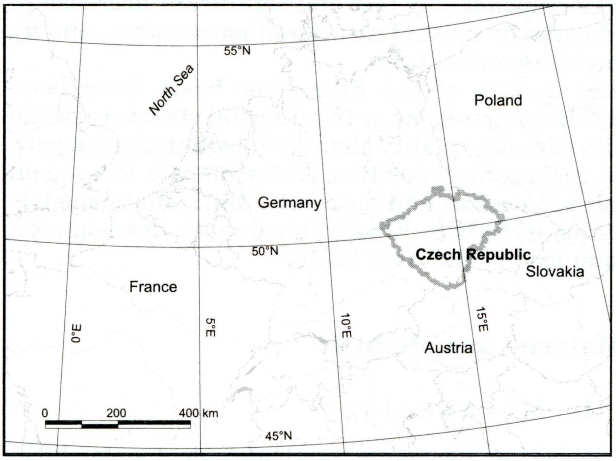

Fig. 1 – Elbe river basin

Dramatic changes in water quality of the Elbe and its river basin came in the 90s. Social changes and opening to international cooperation after 1989 resulted in adoption of fundamental measures to remedy ecological damage. Under coordination of international and national programmes, in particular the International Committee for the Elbe Protection and Projects Elbe I and II, the biggest pollution sources were eliminated and water quality in the Elbe quickly improved.

3. Results

3. 1. Spatial Distribution of Pollution Sources

The Czech part of the Elbe river basin is characterised by high concentration of anthropogenic activities representing current sources of surface water pollution, i.e. mainly urban and industrial complexes distributed along the whole river and its tributaries. Many of them and particularly chemical plants belong among the biggest direct pollution sources in the Czech Republic and Europe.

Spatial concentration of point emission sources in the Elbe river basin copies distribution of main cities and industrial zones. This is also documented by a map of point emission sources (Fig. 2) made on the basis of spatial combination of the SVHB database and the Digital Water Management Map. Along the Elbe river basin, there are 1600 recorded point pollution sources while the most significant emission sources located mainly along large watercourses are concentrated into so called emission areas, i.e. areas of concentrated substance deflation of emissions from point sources to watercourses with similar characteristics of the structure of pollution sources and emitted pollutants.

Besides the sources concentrated in the key areas, there are almost 1 400 recorded point emission sources with annual volume of emitted sewage water over 1 000 m^3. Such local industrial and municipal point emission sources, often drained to recipients with low water volume, affect the already high pollution load transferred from headstream to downstream areas and multiplied by non-declining load from nonpoint pollution sources.

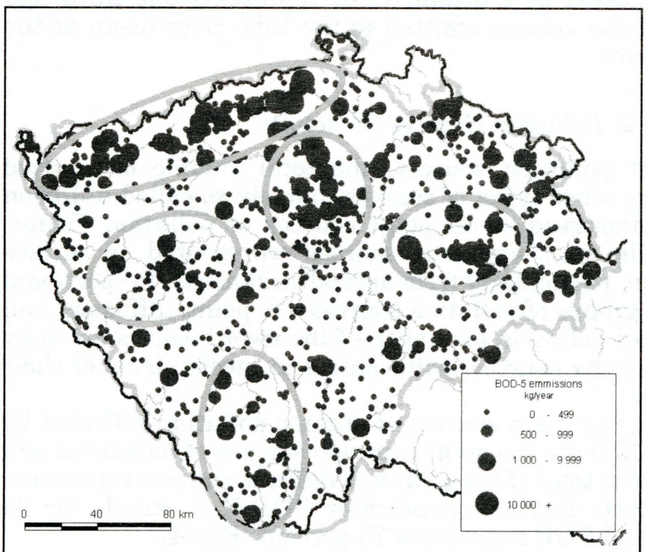

Fig. 2 – Main emmission areas. BOD–5 emmissions (kg/year)

3. 1. 1. Development of Pollutants Emissions

In the course of the 90s, the Elbe river basin experienced a significant decrease

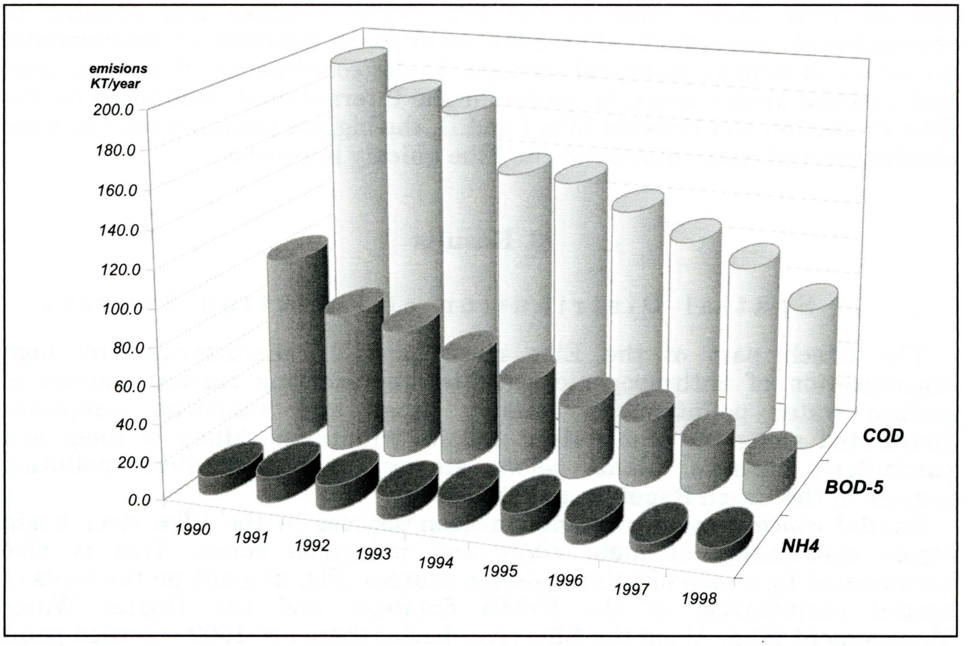

Fig. 3 – Decreasing pollution load from point sources

in pollutants emission volume from recorded point pollution sources. Construction and intensification of sewage treatment plants in big industrial and communal emission sources resulted in radical fall of emissions according to parameters reflecting this type of pollution load (Fig. 3). The indicator of organic pollution, BOD-5, showed reduction of overall recorded emissions from 1990 to 1999 down to one fifth of original volume. Emissions volume at the end of the 90s as reflected by indicator COD represents one third and indicator NH_4 one half of the volume emitted to the Elbe river basin at the beginning of the same period.

3. 1. 2. Pollution Sources Structure

Besides recorded point pollution sources, the total volume of emitted pollutants is comprised by other types of sources, namely so-called diffusion sources represented by dispersed small point sources of pollution (farms, small settlements, landfills etc.), and area sources represented by surface runoff from the river basin, particularly from agricultural areas. Proportional participation of the main groups of pollution sources, i.e. point, diffusion, and area sources, in the overall pollution load of the Elbe river basin is given by different characteristics of the sources, pollutants and mechanisms of their transport to surface water.

In the Elbe river basin, the main sources of organic pollution reflected by indicators of BOD-5 and COD are the point emission sources of industrial and municipal character, and the total of big point and diffused sources represents the majority of the balance. Regarding indicator BOD-5, it stands for 95 percent of the total load and COD represents 75 percent (Fig. 4).

Similar proportions are characteristic for the total phosphorus – almost 60 percent is produced by recorded point sources, 35 percent by diffused sources,

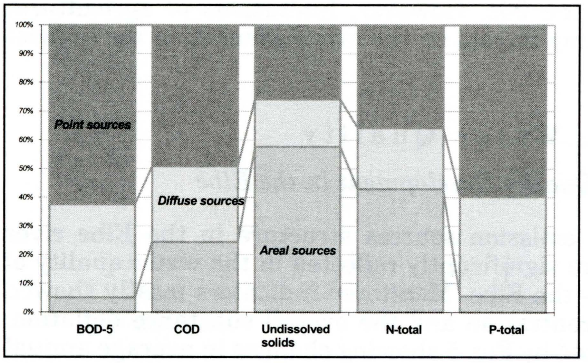

Fig. 4 – Pollution sources structure

and only 5 percent by area sources. The issue of phosphorus transport is quite complicated and therefore these values shall be interpreted taking into account that different authors achieve different final values of the indicator, e.g. Jurča a kol. (1997), or Behrendt and Nesměrák (1996).

Pollution load of the Elbe river basin by whole nitrogen and undissolved substances is mostly generated by transport from area and diffused sources. Regarding total nitrogen, load from area sources represents almost 45 percent of the total amount emitted in the Elbe river basin and jointly with diffusion sources stands for 65 percent of total emissions. This parameter is however comprised by two indicators of different origin and transport mechanism, i.e. by $N\text{-}NH_4$ and $N\text{-}NO_3$. While $N\text{-}NH_4$ shows clear dependence on point pollution centres, $N\text{-}NO_3$ load is generated mostly by area sources.

The indicator of undissolved substances is most closely related to nonpoint sources and general erosion processes. In terms of this parameter, 65 percent of emitted load is generated by area sources that together with diffusion sources represent 75 percent of substance deflation.

3. 1. 3. Changes in Pollution Sources Structure

The structure and participation of main emission sources in the overall Elbe river basin load isn't constant. Significant changes in water quality of the Elbe and its main tributaries occurring in the 90s were accompanied by radical changes in the source structure. Structural development of emissions is mostly marked by fast decline of point sources impact. Regarding industrial sources, the pollution volume emitted at the end of the 90s represented only one sixth of the amount detected at the beginning of the period. Decline in volumes emitted by municipal sources was significantly slower due to the lack of sewage plants in large settlements at the Elbe downstream in the 90s. Nevertheless, emissions even in this respect were reduced in the period down to 1/3 of the original volume.

To the contrary, emissions generated by diffusion and area sources don't show any significant drop and have increasingly decisive impact on surface water quality in the Elbe river basin.

While the impact of industrial and municipal load sources is falling at different speed on the Elbe itself and other big watercourses in the Czech part of the Elbe river basin, small watercourses don't show such significant changes. They are mostly influenced by diffused small sources, e.g. municipalities lacking sewage systems or sewage treatment plants, farms, smaller businesses etc. The majority of peripheral river basins is subject to increasing impact of area sources, particularly of surface runoff from agricultural areas. The balance volume of pollution in the examined river basins isn't falling despite relatively significant reduction of fertilizers application in agriculture in the 90s. However, limitations of agricultural activities haven't had almost any impact on the areas generating the highest volumes of pollution.

3. 2. Water Quality

3. 2. 1. Water Quality Development in the Elbe

Changes in emissions and emission sources structure in the Elbe river basin occurring in the 90s were significantly reflected in the water quality of the main river of the system – the Elbe. Monitored indicators mostly showed decline in river pollution concentration and the overall substance deflation. This development is documented by Fig. 5 showing changes in average annual organic pollution concentrations according to BOD-5 in the longitudinal profile of the Elbe. From the mid 90s, the critical load level was continuously cut down in the Elbe midstream and downstream, and at the end of the period water of the whole stream reached the level achieved at the turn of the 90s only in the Elbe upstream.

In the 90s, the Elbe generally showed visible decrease in concentration and substance load according to selected water quality parameters, particularly those reflecting load from point pollution sources. This concerns indicators reflecting the overall contamination in COD, BOD-5 and $N\text{-}NH_4$ indicators. Mainly in the second half of the 90s, they showed radical decline of the Elbe river basin load due to dramatic cuts of big industrial and municipal sources emissions.

The process of contamination by total phosphorus is different. In the 90s, this indicator reflecting the load volume caused by industrial and mainly municipal point sources showed not only stagnation, but also contamination increase in certain areas. Slow increase in phosphorus load doesn't concern only the Elbe, but also partial river basins of its tributaries. This situation is caused by increased phosphorus emissions by municipality sources and lack of sewage treatment plants in small and medium size villages and their technical state. In terms of the total balance, decrease in phosphorus emissions caused by big industrial and municipal sources at the Elbe and its main tributaries didn't absorb increased load from the whole river basin.

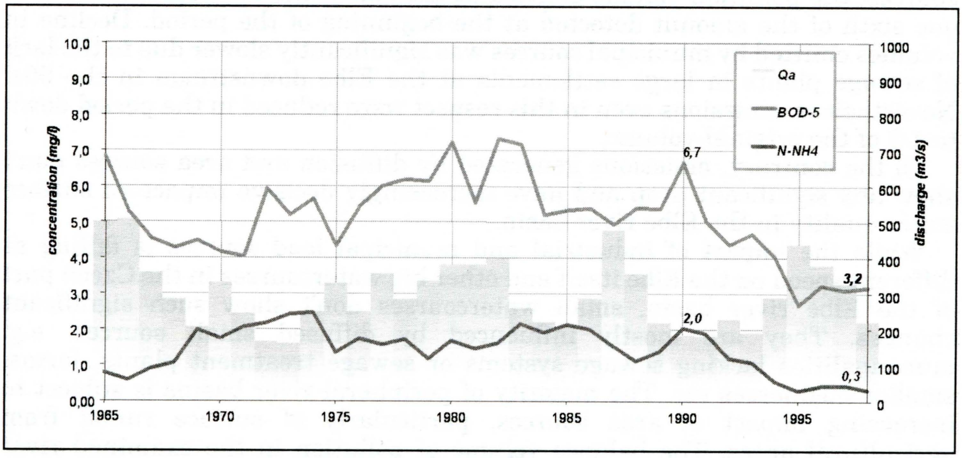

Fig. 5 – Pollution concentrations decrease in Elbe river at Děčín

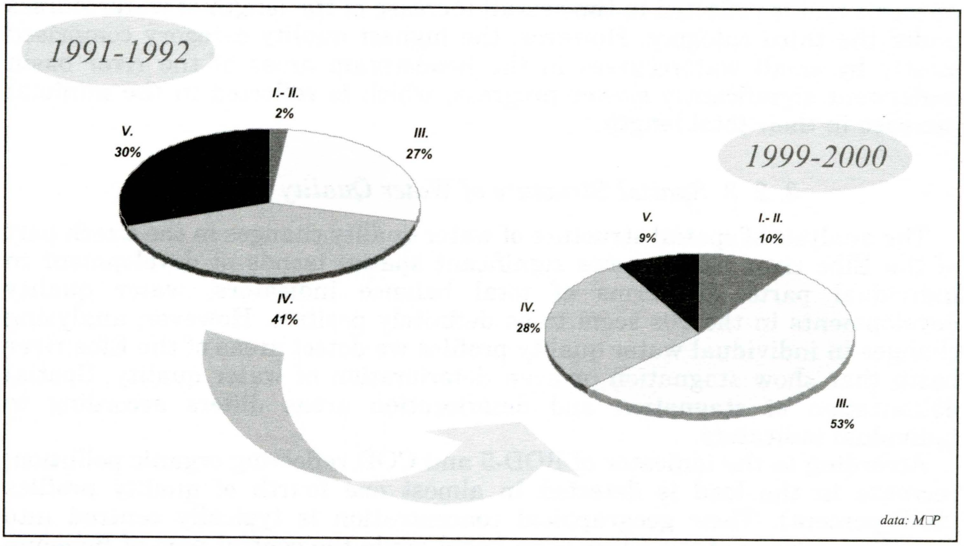

Fig. 6 – Overall water quality changes in Elbe river basin

Indicators reflecting pollution load from area sources, mainly indicators of N-NO_3, didn't show any significant quality changes in the 90s. Supply of nutrients from source surfaces didn't fall despite evident suppression of agricultural activities and fertilizers application in the 90s.

3. 2. 2. Water Quality Changes in the Elbe River Basin

Changes in water quality weren't recorded only in the Elbe, but positive improvements, although of different intensity, involved the whole river basin. The overall quality of watercourses of the Czech part of the Elbe river basin, expressed in quality categories (Fig. 6), was significantly improved. Comparing the number and total length of watercourses included in one of five quality categories at the beginning and in the end of the 90s, three tendencies emerge:

- There are significantly less watercourses classified in the two worst quality categories. Watercourses reaching such a strong pollution level in 1991–92 represented in total 71 percent of the hydrographic network, while in 1999–2000 it was only 37 percent.
- In comparison with the beginning of the 90s, the number of sections of watercourses classified in the third category as polluted water doubled.
- The length of watercourses sections classified in the two best categories increased by 8 percent. It is a positive trend, but a relatively small change against the overall scope of quality changes.

Data on overall water quality changes in watercourses of the Elbe river basin (Min. of the Environment 2001) provide a comprehensive picture of the river basin and the internal structure of changes in individual river basin parts. The sections falling under the fourth and fifth category at the turn of the 90s were mostly on big rivers, on the Elbe and its main tributaries that are subject to big industrial pollution sources. Improvement of water quality resulting from construction and intensification of sewage treatment plants at such sources shifted water quality in recipients by one or two categories upwards and is reflected in the overall increase of the length of watercourses under the third category. However, the highest quality category comprised mostly by small watercourses in the headstream areas of the river basin underwent significantly slower progress, which is reflected in the minimal increase in their total length.

3. 2. 3. Spatial Structure of Water Quality Changes

The analysis of spatial structure of water quality changes in the Czech part of the Elbe river basin shows significant spatial trends of development in individual parts. In terms of total balance indicators, water quality developments in the 90s seem to be definitely positive. However, analysing changes in individual water quality profiles we detect areas of the Elbe river basin that show stagnation or even deterioration of water quality. Spatial delimitation of stagnation and deterioration areas differs according to individual indicators.

According to the indicator of BOD-5 and COD reflecting organic pollution, increase in the load is detected in almost one fourth of quality profiles (22.7 percent). Their geographical concentration is typically centred into boundary regions of the Elber river basin while the central part of Bohemia including Prague region records decrease of pollution (Fig. 7).

The indicator of nitrate pollution shows different spatial trends of pollution load evolution. The overall balance of nitrate pollution load is stagnating and

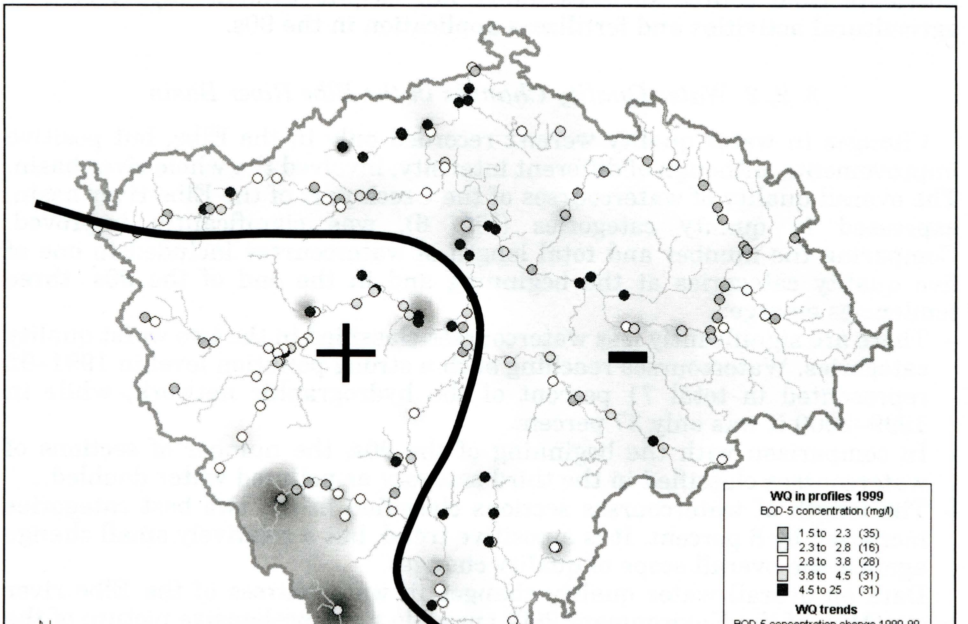

Fig. 7 – Changing patterns of water quality in Elbe river basin, BOD-5. + ... rise of concentrations, - ... decrease of concentrations. WQ in profiles 1999, BOD-5 concentration (mg/l). WQ trends, BOD-5 concentration change 1990-99.

regional comparison doesn't show any significant decrease in overall pollution either. Almost one third of water quality profiles suffer quality deterioration while remaining profiles development is marked by stagnation and minimum concentration decline. It is worrying that concentration rise occurs in already burdened areas classified under 3rd and 4th water quality categories.

Overall spatial trend in nitrate concentration development points to deep problems of links between agriculture and water quality. Globally, the 90s saw a significant suppression of agricultural activities in the Czech Republic, but it didn't result in expected decrease in nutrients and mainly nitrates load. Decline related to agriculture limitation and fertilizers application was set off by intensified activities of economically stronger entities. Unlike in case of industrial and municipal sources, here the decline isn't brought by systematic changes. Further economic upsurge of agricultural entities facilitated for example by future EU subsidies is likely to result in increased use of fertilizers and effective pesticides and deterioration of water quality in small and medium watercourses.

4. Discussion

Radical reduction of emissions in the mid 90s caused fast and significant decline of the Elbe river basin pollutants load. After reaching certain level it however seems that further emissions reduction won't have the same response of falling concentration of main monitored pollutant indicators in rivers. It isn't clear whether and how further water quality improvement in the Elbe river basin can be achieved in the future.

Answers can be found through structurally differentiated view of water quality changes and tools of mathematical modelling. Geostatistical analyses of links between river basin geographical location, its size and water volume, and water quality changes clearly points to differences in development of watercourses belonging to different classes. The majority of positive changes occurred on the biggest watercourses influenced by large industrial and urban point pollution sources. Medium watercourses influenced mostly by local industry and settlements are undergoing a very variable process often directly linked to the overall regional economic situation. The slightest changes, often of a negative character, were detected in small watercourses in agricultural areas.

There are more explanations of highly asymmetric load decline of the Elbe river basin in the 90s, differing by various classes. The fact that most activities aiming at water quality improvement were focused on the biggest rivers had economic, technological and political motives.

Measures to reduce emissions from point sources, i.e. construction or intensification of sewage treatment plants, although economically demanding, are easy to adopt from the technical point of view, and ensure relatively high effectiveness against the invested value. To quickly eliminate the massive volume of pollution leaving the Czech Republic through the Elbe at the beginning of the 90s, remediation of big direct industrial and municipal emission sources on the Elbe and its main tributaries was the only solution. Interest in increased water quality of the Elbe wasn't expressed only by the Czech Republic, but also by Germany and the EU who monitored how remediation of emission sources on the Elbe was reflected by pollution decrease in North Sea, and therefore financially supported construction and modernisation of sewage treatment plants in the first half of the 90s.

On the other hand, smaller watercourses still suffering from local industrial and municipal pollution are less visible and mostly outside the interest of general public and international institutions. These courses, representing the largest part of the Elbe hydrographic network, were subject to massive riverbed modifications, channelization, and melioration in the past and lost their natural abilities to eliminate load caused by anthropogenic activities. Financing of construction and reconstructions of sewage treatment plants in municipalities and industrial facilities in these areas is far more complicated and takes longer. What's more, small and medium watercourses are highly influenced by nonpoint pollution sources difficult to reduce and eliminate without an integrated package of economic, legal, executive and technical measures with a long-term effectiveness.

Processes occurring in the Czech part of the Elbe river basin are analogical to those happening on European rivers. Assessment of water quality in European rivers performed by the European Environment Agency (EEA 2002) shows similar links between watercourse classes and their quality. Regarding total phosphorus and nitrogen, the highest average concentration is detected on the smallest watercourses as in the Czech part of the Elbe river basin. The larger the river basin area and average long-term discharge, the higher the overall water quality and dynamics of pollution decline.

5. Conclusion

The results of analysis of water quality state and developments in the Czech part of the Elbe river basin in the 90s, and the processed development prognosis have shown that increasing differences between water quality in the Elbe and its tributaries currently represent the main problem for further water quality improvement in the given area.

Decrease in pollution level of the Elbe in the 90s doesn't result from positive development of the whole river basin, but only from activities along the Elbe itself and the main tributaries. At the beginning of the 21st century, the majority of hydrographic network of the Czech part of the Elbe river basin, mainly small watercourses in peripheral areas, still remain exposed to high emissions from local industrial and municipality pollution sources and agricultural production.

Point pollution sources underwent radical quality changes in the 90s, which however doesn't apply to diffusion and area sources of surface water pollution. Non-declining emission volume from diffused agricultural and small municipal sources, distributed by the network of devastated small watercourses, hinders natural retention and elimination of pollutants. The areas of small watercourses thus should be at the centre of future attention because permanent improvement of downstream water quality can't be achieved without changes of the headstream area.

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Shrnutí

ZMĚNY KVALITY VODY V POVODÍ LABE

V průběhu 90. let došlo v české části povodí Labe k zásadnímu obratu ve vývoji kvality povrchových vod. Po dlouholetém nárůstu úrovně znečištění došlo díky snížení emisí z hlavních průmyslových a komunálních zdrojů k poklesu úrovně zátěže Labe i jeho nejdůležitějších přítoků. Rozsah a rychlost těchto změn v kvalitě vody je bezprecedentní jak v rámci ČR, tak i v evropském měřítku.

Pokles úrovně znečištění však je však omezený víceméně pouze na Labe a jeho hlavní přítoky. Velká část drobných vodních toků, zejména v zemědělské krajině i nadále trpí nadměrným znečišťováním z průmyslových a komunálních zdrojů, stejně jako intenzivní zemědělskou výrobou.

Pro další pokračování poklesu znečištění Labe bude rozhodující dokončení eliminace emisí z komunálních zdrojů a postupné snižování zátěže, přinášené do Labe jeho přítoky. Tyto v současné době představují bilančně bezkonkurenčně největší zdroje látkových vnosů do toku Labe. S výjimkou Vltavy a Bíliny, které jsou pod vlivem silných bodových zdrojů je kvalita vody většiny z nich ovlivňována plošnými a difúzními zdroji znečištění. Na rozdíl od bodových zdrojů znečištění, které v průběhu devadesátých let prodělaly kvalitativní skok, v oblasti difúzních a plošných zdrojů znečištění povrchových vod k analogickému vývoji nedošlo. Neklesající objem emisí z rozptýlených zemědělských i drobných komunálních zdrojů, odváděných sítí zdevastovaných malých vodních toků, neumožňuje přirozenou retenci a odbourávání znečišťujících látek. Vodní toky jsou díky tomu vystaveny silné zátěži často již od svých pramenných úseků, přičemž celkově vysoká intenzita využití krajiny působí na postupně rostoucí zátěž celého říčního systému.Celková postupná rehabilitace stavu přírodní sféry povodí Labe je procesem s podstatně delším časovým horizontem, než představuje náprava kvality jeho vodní složky. Realizované modely a prognóza vývoje ukázaly na limity v procesu zlepšování jakosti vody prostřednictvím omezování emisí z bodových zdro-

jů znečištění. Další pokles znečištění vody v Labi i při důsledné aplikaci moderních čistících technologií a dodržování emisních limitů může přinést již jen dílčí zlepšení jakosti vody.

Těžiště prací na rehabilitaci kvality vody v toku se proto bude muset přesunout z vlastního koryta toku do jeho celého povodí. Při pokračující eliminaci zátěže z přímých bodových zdrojů bude pro další snížení znečištění vody nezbytný komplexní přístup k řízení kvality vody v povodí, podchycení a eliminace rozptýlených drobných bodových zdrojů znečištění a posilování přirozených funkcí říčních ekosystémů, včetně jejich postupné revitalizace.

Obr. 1 – Povodí Labe
Obr. 2 – Hlavní emisní oblasti povodí Labe (emise v kg/rok)
Obr. 3 – Pokles emisí znečištění z bodových zdrojů, osa x – roky, osa y – emise (tisíce tun/rok)
Obr. 4 – Struktura zdrojů znečištění. Podíly (ve sloupci odspodu): plošné zdroje, difúzní zdroje, bodové zdroje; sloupce (zleva): BSK5, CHSKCr, nerozpuštěné látky, Ncelk, Pcelk
Obr. 5 – Pokles koncentrací znečištění v profilu Labe–Děčín. Osa x – roky, osa y – vlevo koncentrace (mg/), vpravo průtok (m^3/s).
Obr. 6 – Změna tříd jakosti povrchových vod v povodí Labe
Obr. 7 – Změna prostorové struktury kvality vody povodí Labe v ukazateli BSK5. + – nárůst koncentrací, - – pokles koncentrací. Body – jakost vody na profilech v roce 1999, koncentrace BSK5 (mg/). Plošně – změna kvality vody v ukazateli BSK5 v období 1990-99.

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