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(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)

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60 years ago in VTEI

One of the important topics of the professional section of the February issue is the topic of wastewater. For this reason, we have chosen an article from our archive by Ing. František Šedivý from the Ministry of Agriculture, Forestry and Water Management. the article „Joint industrial and municipal wastewater treatment plants" was published in VTEI in 1961.

Due to the substantial expansion of industrial and agricultural production, as well as the increase of living standard, demands for water are growing, the amount of wastewater is growing, and the quality of water in our rivers is constantly deteriorating.

In order to prevent further pollution of streams, several hundred wastewater treatment plants will be built in the third five-year plan. Eliminating the main sources of pollution will require billions in investment costs, as well as significant operating costs. This requires that the construction of treatment facilities be carried out economically and that the operating costs of the treatment plants be kept as low as possible while achieving the maximum cleaning effect.

One of the possibilities for making the construction and operation of treatment facilities economical is the construction of joint industrial wastewater treatment plants with municipal sewage. By joining treatment plants of both types of wastewater, it is possible to create a larger investment unit, which provides the prerequisite for the implementation of the joint work to be carried out more economically than it would be the case with two separate treatment plants at separate locations. the advantage of one location must be economically assessed even in those cases where joint cleaning in one treatment plant is not possible for technological reasons.

The investment costs for a joint treatment plant or for two treatment plants next to each other are reduced by building common auxiliary operations, one access road, one electricity and water connection. the costs of fencing, internal network distribution and communication are also proportionally reduced. When building a joint treatment plant, however, the costs of building a sewage network usually increase substantially. Here, it is primarily necessary to assess whether it is possible to discharge industrial waste water without pre-treatment into the common sewer and to consider its effect on the sewer material.

However, the economic balance of the sewage network must be assessed not only in terms of investment costs, but also in terms of hygiene and aesthetics, depending on local conditions. For example, it will be advantageous for industrial wastewater from plants located above or in the town, if the situation and high-altitude location allow, to be led to a treatment plant below the town, even if this solution will not be the most economical.

Savings on operating costs for joint treatment plants or for two treatment plants on one construction site can be achieved by the fact that there are better conditions for the use of mechanization in a larger operating unit. Joint auxiliary operations enable better use of specialized service professions, and thereby also improve the quality of the treatment plant,s operation. In most cases, it will be possible to replace chemical treatment of industrial wastewater with biological treatment, which is usually more economically advantageous and does not burden the national economy with the consumption of significant amounts of chemicals. Biological sludge is also more usable for agriculture.

Co-treatment of industrial wastewater with municipal sewage may in some cases be the most economical way to treat this wastewater. the construction of joint treatment plants is particularly advantageous where, due to the low water content of the recipient, it is necessary to biologically treat industrial wastewater.

When assessing the possibility of building joint facilities, however, it is first and foremost necessary to assess whether the treatment of mixed wastewater is technologically possible and whether it is sufficiently research-verified. It is not possible to allow the construction of joint treatment plants just because this solution reduces investment and operating costs without guaranteeing the cleaning effect and stability of operation.

The construction of joint treatment plants can also only take place in those cases when the deadlines for the elimination of significant sources of pollution are not significantly extended, thereby reducing the volume of investment construction of treatment plants in the first years of the third five-year plan and jeopardizing the fulfilment of the task of achieving a fundamental turnaround in water purity by 1965.

By building joint treatment plants, it is possible to achieve significant financial savings. For that reason, it is necessary for planners and water management authorities to constantly deal with connecting treatment plants and to apply joint wastewater treatment wherever it is beneficial.

From TGM WRI archives

VTEI Editorial office

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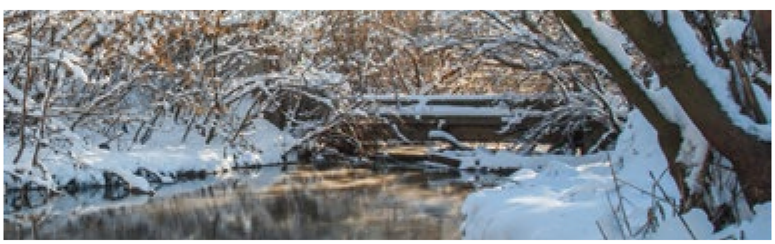

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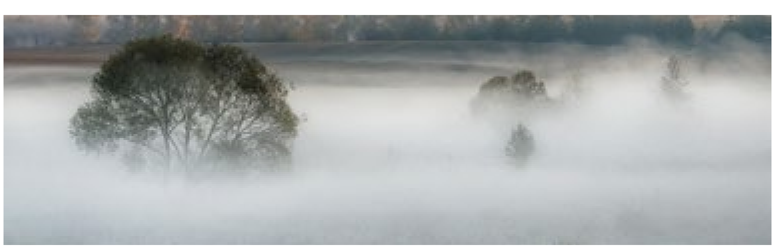

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Dear readers,

You are receiving the first issue of our VTEI journal in 2024. Let me thank you for your patronage in the past year and wish you all the best for the new year, lots of health and fulfilled wishes, but also perseverance in the care of water and the environment. I hope you enjoy reading the VTEI journal as well as working for our Institute, which I appreciate very much.

Many changes await us this year; these are, for example, the amendment to the Municipal Wastewater Treatment Directive, the amendment to the Water Act, the Nature Restoration Law, etc. Even though we may be worried about all of this, let us try to take it as a challenge, as an opportunity to use these changes to make a difference. We do not have to set big global goals from the beginning and want change right away. We can start, for example, locally – so that all of us and our loved ones live well in an environment that is minimally polluted and, at the same time, safe and diverse. Subsequently, we can try to achieve the same goals on a national and international scale. I believe that we can manage it through mutual cooperation, as well as sharing results and information about the implemented projects, which is exactly what our journal helps to do.

I wish you all a pleasant and inspiring read, and success and perseverance in your work and endeavours!

With respect

Ing. Tomáš Fojtík
TGM WRI Director

Benefits and risks of using sludge from small WWTPs after processing by composting for the production of selected types of vegetables

MILOŠ ROZKOŠNÝ, HANA HUDCOVÁ

Keywords: domestic wastewater treatment plant — small wastewater treatment plant — sewage sludge — sludge composting — compost utilization — pot experiments — vegetables

ABSTRACT

The aim of the study, the results of which are presented in this article, was to assess the possibility of simplifying treatment and stabilisation procedures of sewage sludge from small municipal sources of pollution (domestic and small WWTPs up to about 1,000 EP) at the place of their origin and their subsequent use through extensive composting. The results demonstrated the benefit of the application of composts from a material base containing sludge from small WWTPs in increasing the production of the monitored types of vegetables. However, especially with lettuce, there was a higher transmission of selected risk elements. We therefore do not recommend the use of composts with sludge for growing leafy green vegetables. In contrast, this risk did not arise with fruit and vegetables. For practical use, it is still necessary to assess the rate of transfer of other pollutants, such as drug residues and microplastics.

INTRODUCTION

Sludge from wastewater treatment represents a valuable source of nutrients, but at the same time contains a number of hazardous elements, organic pollutants, and other substances. In its raw state, it is loaded with relatively significant microbial contamination. As part of the principles of the circular economy, the possibilities of limiting its contamination, as well as its stabilization and processing into substrates that can be used in agriculture, or in the care of green areas and greenery in general, have been studied for a long time. Restrictions on the use of sewage sludge in European countries are presented in the paper [1]. A summary overview of the restrictions on the application of sludge in agriculture, which is based on the valid European directive from the 1980s, and an overview of the management of sludge in EU member countries as of 2019 is given in Hudcová et al. [2]. The direct use of sludge and indirect use after processing by composting is very different in the EU member states and corresponds also to local conditions and how individual countries approach the risks of using sludge on land. The main danger associated with the application of sludge on agricultural land is the potential long-term accumulation of toxic substances [3], which can then be taken up by crops. Composting is one of the options for pre-treatment of sludge and other waste from water treatment processes, which should bring about modification of their properties [4, 5].

Composted sludge is a source of a whole range of nutrients for plant growth (e.g. phosphorus, nitrogen), organic matter, and microorganisms useful for the soil. Its use reduces the consumption of fertilizers and pesticides and improves the physical and biological properties of the soil; however, at the same time, excessive application can lead to the accumulation of heavy metals in the surface layers of the soil [6]. During composting, which is the aerobic biological decomposition and stabilization of organic substrates, microbial populations develop which cause numerous physico-chemical changes in the mixture. Composting can reduce the volume of the mixture by 40–50 %, effectively destroy pathogens through the metabolic heat generated by the thermophilic phase, degrade large amounts of hazardous organic pollutants, and provide a final product that can be used as a source of organic matter, slow-release nutrients, and trace elements for the soil [7–12]. Sewage sludge is often composted before application to the soil, also with the aim of reducing the availability of heavy metals, as this process results in the mineralization of organic compounds that control the availability of cations to plants [13].

There is a general consensus in the scientific literature that aerobic composting processes increase the complexation of heavy metals in organic waste residues and that metals are strongly bound to the compost matrix and organic matter, limiting their solubility and potential bioavailability in soil. The most strongly bound is Pb, the weakest are Ni and Zn, Cu and Cd, which show moderate sorption characteristics. Metal availability decreases with composting time and maturation [14].

The aim of the study, the results of which are presented in this article, was to assess the possibility of simplifying treatment and stabilization procedures of sewage sludge from small municipal sources of pollution (domestic and small WWTPs up to about 1,000 p.e.) at the place of their origin and their subsequent use through extensive composting. The result should also be to assess the benefits and risks when applying the resulting composts for growing selected types of crops (vegetables) on a community scale. The study was thus intended to supplement information for decision-making; namely, whether it is possible to consider a different method of local processing and utilization of sludge from the mentioned types and sizes of WWTPs than the standard procedure consisting of regular transfer to a larger WWTP with sludge management.

METHODOLOGY

For the presented study of the effect of composting sludge and waste from reed bed plants on the transfer of nutrients and pollutants to selected types of vegetables, sludge and waste from domestic and small WWTPs of two basic technologies were used: activation WWTPs and reed bed plants. A more detailed description of treatment plants that are the subject of long-term research, as well as an overview of conclusions from detailed analyses of their sludge, are given by the authors in other publications [15, 16].

Material and composition of experimental composts

With regard to the simulation of the possible actual process of treating sludge from domestic and small WWTPs as part of composting with other organic materials from smaller sources (domestic biowaste, community biowaste), we chose to carry out composting in plastic composters with a volume of several hundred litres (*Fig. 1*) and in small trapezoidal piles of material of a similar volume, covered with a foil.

In the first year, two composts were created in plastic composters with a volume of 500 litres: one with sludge from the domestic activated WWTP (marked K-AČ) and the other with sludge from the reed bed plant (marked 1 K-KČ). In the case of sludge from the reed bed plant, one more experimental pile of material was prepared in the form of a trapezoidal pile under foil, with a volume of 4,000 litres. The compost was marked as 2 K-KČ. Layers of sludge in a total volume that corresponded to the principles established by the ČSN regarding composting (i.e. a maximum sludge content of up to 40 % of the pile) were interspersed with layers of grass from mowing, layers of chips from processed wood matter and, in the case of a reed bed plant, also with additional layers of macrophyte vegetation from reed bed filters of the plant (reed with an admixture of iris and great manna grass). The ratio of input materials corresponded to the requirement for the recommended C/N ratio, which is reported in the range of 20 to 30/1 [17, 18], while the addition of green and wood matter during sewage sludge composting aimed to increase the C/N ratio [19].

In the second year, composts were established in trapezoidal piles covered with PE black impermeable foil with a volume of about 300 litres using sludge from two sizes of reed bed plants (domestic – compost K-3 and municipal – compost K-4). The layers were placed as follows: bottom layer 10 cm – wilted grass, above it a 5 cm layer of sludge from the reed bed plant (dry sludge about 14 %), above that a 15 cm layer – wilted grass, then a 5 cm layer of sludge from the reed bed plant (dry sludge about 14 %) and the upper layer consisted of a 10 cm layer of wilted macrophytes. The description of the municipal reed bed plant is given in Rozkošný et al. [20].

Fig. 1. Composting containers used for community composting (left); one of the final compost mixtures for the pot experiments (right)

During the composting process, the ambient air temperature and the temperature and humidity of the environment in the compost were monitored.

During composting, mixed samples of the resulting compost were taken to analyse the current level of microbiological contamination (enterococci, faecal coliform bacteria) and the content of nutrients and macroelements (N, P, K, Ca, Mg, Na) and heavy metals (Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn). Dry matter, loss by annealing, and the content of culturable microorganisms at 22 °C were also monitored. Sampling took place for composts established in the first year after four and twelve months from establishment; for composts established in the second year after four, seven and twelve months from establishment. The length of the composting process corresponded to experience with the course of extensive small-volume (domestic, community) composts, which are characterized by a longer period of maturation and stabilization.

Assessment of the effect of composts on the production of selected crops

Assessment of the effect of composts on the production of selected crops was carried out using pot experiments. Among the studied crops (also on the basis of research), crops representing different types of vegetables (leaf, fruit) were selected: lettuce (*Lactuca sativa* L.) – *Maršalus* variety (*Fig. 2*) and tomato (*Lycopersicon esculentum* Mill.) – *Tornado* F1 variety (*Fig. 3*). Lettuce is one of the most commonly consumed raw leafy vegetables [24] and is classified as a plant sensitive to heavy metals [21–23]. Tomatoes are the second most important vegetable in the world after potatoes; in 2016, annual global production was 177 million tons grown on almost 4.8 million ha of land [24].

Pot experiments for growing selected types of vegetables

Pot experiments were designed using the same five-litre plastic pots with a surface area of 0.031 m^2. All sets were placed in the same location and under the same conditions. Two (experiment 1 year) or three repetitions (experiment 2 year) were prepared for each variant of the substrate (soils, composts, mixtures of soils and composts). Substrates were chosen to include comparative soils – fertile garden soil (chernozem – Hustopečsko region), designated as ZZ in the experiments, and degraded eroded field soil (chernozem – Hustopečsko region), designated as EZ in the experiments. Then there were mixtures of these soils with composts, and only composts. Soils and composts were homogenized by mixing before being filled into containers, and portions were subsequently placed into individual containers. The materials were prepared in a rainless period with the following humidity levels: first year experiment – soils about 94 % dry matter, composts about 73 %; second year experiment – soil about 94 % dry matter, composts about 74 %. Mixtures of field soil with composts were prepared in such a way that the proportion of compost corresponded to the theoretical field dose of 80 tons of compost per hectare. After conversion, it was 260 g in one five-litre container. The amount of soil in the mixture weighed about 3 kg. The proportion of compost in the mixtures was about 8 %. The compost was always mixed with the soil individually when filling each container, incorporating it into the upper layer of the soil to a depth of about 5 cm (*Fig. 2*).

Fig. 2. View of part of the containers from the lettuce planting pot experiments; mixing of compost with soil in the upper layer of about 5 cm is evident

Processing and analysis of vegetable, soil, and compost samples

Lettuce was harvested about one month after planting the seedlings (May), at the time of full maturity of the lettuce heads before their transition to the phase of flower formation (*Fig. 4*). Tomato plants were planted on the same dates as the lettuce. Harvesting of tomato fruits took place from the first appearance of ripening fruits (July) until the end of production of ripening fruits (September, October). Lettuce samples were dried at room temperature, finely crushed, and homogenized. Harvested tomato fruits were weighed fresh and stored in a freezer. At the end of the harvest, all fruits from a given plant were mixed, processed in the laboratory into a homogeneous mixture, and freeze-dried to take sample portions for analysis. To determine Al, As, Cd, Cr, Cu, Ni, Pb, Na, K, Ca, Mg, Fe, Mn and Zn, each sample (about 1g) was mineralized in a Teflon container by MLS-1200 MEGA device using 3 ml of concentrated HNO_3 and 1 ml of 30% H_2O_2. The containers were sealed for the mineralization cycle to take place. After cooling, the contents of the container were transferred into a 100 ml volumetric flask. The determination of Al, As, Cd, Cr, Cu, Ni, and Pb was carried out by the method of atomic absorption spectrometry – electrothermal atomization (AAS-ETA) on a PERKIN ELMER AANALYST 600. The determination of Na, K, Ca, Mg, Fe, Mn and Zn was carried out by the method of flame atomic absorption spectrometry (AAS-flame) on a PERKIN ELMER AANALYST 400. The calibration curve method was used to determine the content of individual metals. The correctness of the determined concentrations was verified using the simultaneous analysis of internal and reference material. Determination of Hg was carried out on an AMA-254 mercury analyser, calibrated according to the manufacturer's manual. Approximately 0.1 g was weighed from the pre-treated sample. The Hg content determined always corresponded to the average of two to three simultaneous determinations. The correctness of the determined concentrations was verified using the simultaneous analysis of internal and reference material. Homogenized samples of composts and soils were freeze-dried and then processed in a manner identical to the processing of biomass samples. Total phosphorus was determined using the cuvette test LCK 348 (HACH-LANGE) on a DR 3900 spectrophotometer with a tungsten lamp (Vis). Total nitrogen was determined by the modified Kjeldahl method according to ČSN ISO 11261.

Fig. 3. View of part of the containers from the tomato planting pot experiments

Fig. 4. View of part of the planting pot experiment containers; in the left part, lettuce heads and tomato plants with fruits in a substrate with compost, in the right part in a substrate without compost

Assessment of phytotoxicity of composts using the seed germination test

In the case of using sludge from small sources (domestic and small municipal WWTPs) for horticultural and agricultural purposes, the main interest of the user is also to reduce the contamination of the resulting sludge and to ensure that the substrates used that contain sludge or compost do not pose a health risk and a danger to the environment in terms of toxicity. This fact can be verified, for example, by phytotoxicity tests or earthworm escape tests [25]. Phytotoxicity tests exist in the form of directives issued by major environmental agencies, such as the US EPA (United States Environmental Protection

Agency), OECD (Organization for Economic Co-operation and Development), ISO (International Standards Organization), ASTM (American Society for Testing and Materials), and others. Papers from 2011 and 2019 give an overview of phytotoxicity tests [26, 2].

The seed germination test, which was chosen for our study, is a method of evaluating the intensity of decomposition of organic materials and the maturity of the resulting compost, which was developed at the Crop Research Institute Prague for use in composting practice. It is a biological method of evaluating the phytotoxicity of a sample leachate using the germination index of a sensitive plant – garden cress (*Lepidium sativum*) [27].

The resulting germination index can be obtained from the following equation:

$$IK = \frac{k_v \,.\, l_v}{k_k \,.\, l_k} \; [\%]$$

where: k_v is the germination rate of the sample [%]
k_k control germination [%]
l_v average root length of the sample [mm]
l_k average root length of control [mm]

At values up to 50 %, the index states that the compost is unusable for direct application, from 60 to 80 % it gives the possibility of application with a certain risk of damage to sensitive plants, and at values of 80 % and higher it declares mature compost. If the germination index is between 60 and 80 %, it can be said that the compost is in the conversion phase and has the best fertilizing effect. Above 80 %, this effect decreases, and the influence of humus is stronger, which means that nutrients are more bound. The release of N and P is slower and there is no leaching of nutrients into groundwater [28].

Statistical analyses were performed using available tools in MS Office Excel 2016 and SW R-4. 3. 2. for Windows using ANOVA analysis of variance after pre-screening the data sets for standard distribution. The choice of procedure and statistical methods corresponded to the procedures that were used in a similar experiment focused on the effect of addition of sewage sludge composts to substrates for horticultural purposes [29]. In the case of pot experiments, the evaluation was carried out by calculating statistical characteristics for individual variants of substrates and crops from two (first year) and three repetitions (second year).

RESULTS AND DISCUSSION

Composition and contamination of used soils and composts

The contents of heavy metals and arsenic in the soils used in the experiments in both years did not exceed the preventive and indicative values according to National Decree No. 153/2016 Coll. Of the composts used in the first year, all composts exceeded both the proposed limit value for Cu in the framework of the EU technical report [30] and the given national standard. The composts also exceeded both limit values for Zn, and in the case of K-AČ compost, the limit value for this element was also exceeded according to ČSN 46 5735 [31]. K-3 and K-4 composts used in the second year did not exceed any of the limit values proposed within the EU and given by the ČSN 46 5735 standard. Lower concentrations of Cu and Zn in these composts (on average 218 mg/kg Zn and 65.9 mg/ kg Cu compared to the values of 1,016 mg/kg Zn and 386 mg/kg Cu in the composts in the first year) were probably caused by the lower proportion of used sludge in the input mixture for composting. Sludge load can be affected by the connection to the sewage system, which also brings rain wash rich in these metals due to the corrosion of roofing materials.

Regarding the assessment of microbial contamination, it was carried out using standard analytical methods for the determination of indicator organisms (*Salmonella* sp., enterococci, thermotolerant coliform bacteria) in the input sludge and in the resulting substrates from composting. Microbial contamination of sewage sludge from domestic WWTPs ranged from 2×10^3 to 4.2×10^3 KTJ/g of dry matter of samples in the case of enterococci and 1.6×10^4 to 6×10^4 KTJ/g of dry matter of samples in the case of thermotolerant coliform bacteria. The amount of thermotolerant coliform bacteria in the sludge from the municipal reed bed plant was in the range of 1×10^5 to 2×10^6 KTJ/g of dry matter and the number of enterococci in the range of 1×10^4 to 6×10^6 KTJ/g of dry matter. Microbial contamination in fresh substrates from composts before their use in pot experiments was zero for composts K-3, K-4 and 1 K-KČ (zero detection of KTJ per gram of dry matter) for both indicators. For composts 1 K-AČ and 2 K-KČ in tens of KTJ per gram of dry matter for enterococci and in lower hundreds of KTJ per gram of dry matter for FC. For all composts, it would be acceptable when assessed with the limits listed in the ČSN as "Composting". The presence of *Salmonella* sp. was not detected even in the input sludge.

Phytotoxicity test results

Mixed samples were taken from the set of composts established in the second year (K-3 and K-4) and supplemented with a control sample (seeds germinated only on distilled water) for phytotoxicity seed germination test. Compost samples were already stabilized, they did not show changes in microbial contamination and content of heavy metals and macroelements. The garden cress test was performed in two dilutions, namely 5 × and 10 × dry weight (%). For each sample, 10 Petri dishes with 8 seeds were used, for a total of 80 seeds. After 24 hours, the number of germinated seeds in each Petri dish was determined and the lengths of all roots were measured.

Some vegetative responses, such as the seed germination test or the elongation of root and seedling growth, are commonly used to assess the excess toxicity of organic and inorganic compounds in various substrates [32]. The average germination rate in our experiment was found to be 7.5, 7.5, 7.7, and 7.8 seeds out of 10 for individual prepared mixtures of composts and soils, and 7.8 for the control set. ANOVA analysis showed that the null hypothesis of equality of mean values of the mixtures and the control set could not be rejected at the significance level of $\alpha = 0.05$ ($p < 0.05$). The spread of root lengths between the minimum and maximum values for the prepared mixtures was generally in the same interval of 4.0 to 9.0 cm with average values of 6.6, 6.8, 6.2, and 5.8 cm. The smallest average length (5.4 cm) was achieved by sprouts from the control set. The results of the phytotoxicity test show that the mixtures used were stabilized, without a negative impact on the germination of garden cress seeds. The IK index values ranged from 107 to 118 for all four mixtures.

Effect of compost application on change in yield of useful parts of crops

In the case of containers with lettuce seedlings, the difference in the weight of the above-ground part (leaves) of the grown head of lettuce without damaged and dry leaves on the edge was monitored. In both years, a statistically significant difference in fresh biomass weight was demonstrated (ANOVA, alpha level 0.05). In the first year, the average weight of the fresh head of lettuce was 15.7 g when using the EZ soil and 61.2 g when using the ZZ soil. In containers with 100% compost substrates, the average weight of fresh heads of lettuce was

77.5 g (1 K-KČ), 82.8 g (1 K-AČ), and 99.1 g (2 K-KČ). An 8% admixture of compost to poor-quality soil contributed to a substantial increase in yield. The average weights of fresh heads were 104 g (mixture with 1 K-AČ), 105 g (mixture with 1 K-KČ), and 95.2 g (2 K-KČ). This is an increase of up to 85 % compared to EZ soil, and 36 to 41 % compared to high-quality ZZ soil. An experiment in the second year confirmed these results. The average weight of a fresh head of lettuce when using EZ was 81.4 g, i.e., much higher than in the first year. However, the EZ used in this year contained 38 % more organic matter compared to the EZ used in the first year. In containers with 100% compost substrates, the average fresh weights of lettuce heads were 154 g (K-3) and 108 g (K-4). When using compost K-3, the average yield increased by 47 % when using compost K-4 by 25 %. An 8% admixture of composts to the soil meant an increase in average yields by 27 % (compost K-3) and by 14 % (compost K-4) to values of 111 g (K-3) and 95.3 g (K-4). *Fig. 4* shows the difference in the size of the lettuce heads as a result of the use of compost in growing substrates.

In the case of tomato plants, the influence of cultivation in 100% compost substrates and in soils with admixture of these substrates on the number of fruits obtained during the growing season and the total weight of the fruits was assessed. Fruits were harvested ripe continuously throughout the season, weighed and stored to prepare the resulting mixture for analyses. From the pot experiment in the first year, it appears that tomatoes grown in low-quality EZ soil had the lowest number of fruits (about13 fruits per plant). The yield from ZZ chernozem (about 25 fruits per plant on average) was comparable to the yield of tomatoes growing in a substrate of 100% compost (about 30 fruits per plant on average for all composts used). An 8% admixture of composts to the EZ soil increased the average yield from 13 fruits to 20 fruits per plant. A pot experiment in the second year confirmed the highest average yields from 100% compost substrates, approximately 25 fruits per plant. The yield from EZ was around 15 fruits. Compared to the results from the first-year experiment, the addition of compost substrates to this soil did not significantly increase the yield. Average yields from these mixtures remained at around 15 fruits per plant. In the first year, fruits from plants grown in eroded soil had the lowest total weight (about 300 g per plant on average). In 100% compost substrates, the average fruit weight per plant was 645 g for K-AČ, 755 g for 1 K-KČ, and 650 for 2 K-KČ. The admixture of all types of composts to EZ increased the average mass yields to values of 410 to 495 g, i.e. to the level of quality chernozem ZZ (450 g per plant on average). The fruit weight analysis from the second-year experiment replicated the findings from the fruit number analysis. For 100% compost mixtures, average fruit weights per plant were 700 to 800 g.

Content of selected nutrients and elements in useful parts of crops

Evaluation was done for P, N, K, Na, Ca, and Mg. The element content was measured in dried or lyophilized samples (see above) and determined per kg of dry matter. Subsequently, these values were recalculated using the values of dry matter to fresh matter, both for the biomass of lettuce leaves and for the biomass of fruits from tomato plants. In tomato fruits, a statistically significant difference in content was found for P, Ca, K, Na (both pot experiments of the first and second year) and for N and Mg (pot experiment from the second year). In lettuce leaves, a statistically significant difference in content was found for K and Ca (pot experiment from the first year), but this was not confirmed in the experiment in the following year. In contrast, in this year a statistically significant difference was found for N, P, and Na.

Tab. 1. Average values of heavy metals and arsenic in tomatoes grown in the first-year pot experiment (in mg/kg of fresh matter)

Soil/mixture	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
ZZ	0.55	0.015	0.013	0.039	0.41	2.9	< 0.001	0.55	0.05	0.007	1.5
EZ	0.62	0.017	0.014	0.062	0.58	2.7	< 0.001	0.62	0.08	0.008	1.6
1 K-AČ	0.76	0.020	0.008	0.068	0.81	4.5	< 0.001	0.76	0.10	0.010	3.1
1 K-KČ	0.66	0.018	0.004	0.026	0.89	4.7	< 0.001	0.98	0.04	0.015	3.2
2 K-KČ	0.62	0.017	0.002	0.017	0.80	4.2	< 0.001	0.62	0.10	0.008	3.0
EZ & 1 K-AČ	0.52	0.014	0.006	0.022	0.59	4.1	< 0.001	0.52	0.03	0.007	1.8
EZ & 1 K-KČ	0.60	0.038	0.003	0.024	0.66	4.1	< 0.001	0.60	0.03	0.008	2.3
EZ & 2 K-KČ	0.55	0.015	0.001	0.015	0.65	2.8	< 0.001	0.55	0.07	0.011	1.7

Note: the limit values used for the assessment of contamination are listed in Tab. 3.

Tab. 2. Average values of heavy metals and arsenic in tomatoes grown in the second-year pot experiment (in mg/kg of fresh matter)

Soil/mixture	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
EZ	2.11	0.020	0.012	0.019	0.341	3.1	< 0.001	0.755	0.028	0.012	1.3
K-3	3.59	0.018	0.002	0.018	0.484	4.2	< 0.001	0.683	0.036	0.009	2.0
K-4	2.40	0.026	0.002	0.124	0.517	3.1	< 0.001	0.989	0.038	0.009	2.1
EZ & K-3	3.26	0.021	0.009	0.314	0.367	4.3	< 0.001	1.42	0.043	0.008	1.3
EZ & K-4	0.585	0.016	0.007	0.007	0.340	4.0	< 0.001	0.832	0.088	0.008	1.4

Note: the limit values used for the assessment of contamination are listed in Tab. 4.

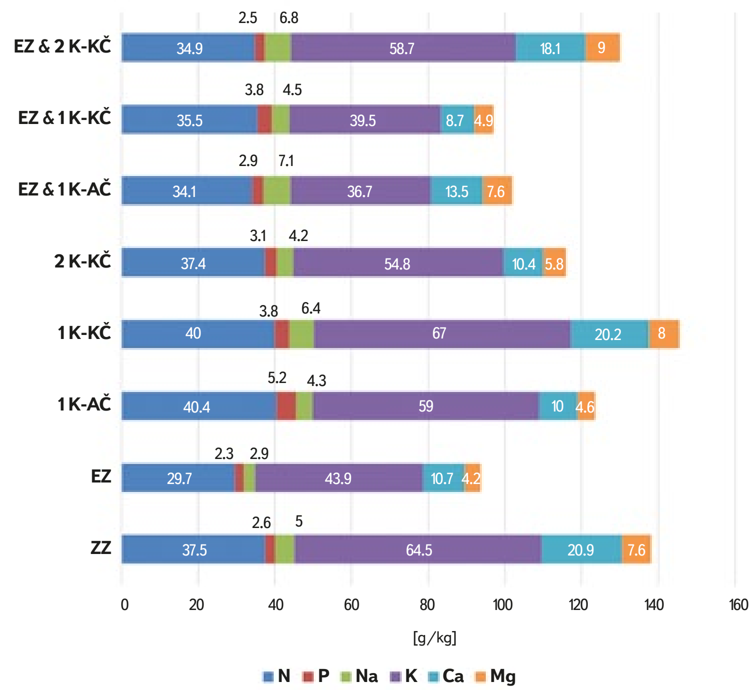

Fig. 5. Average content of nutrients in lettuce heads grown within the first-year pot experiment in g/kg of fresh biomass

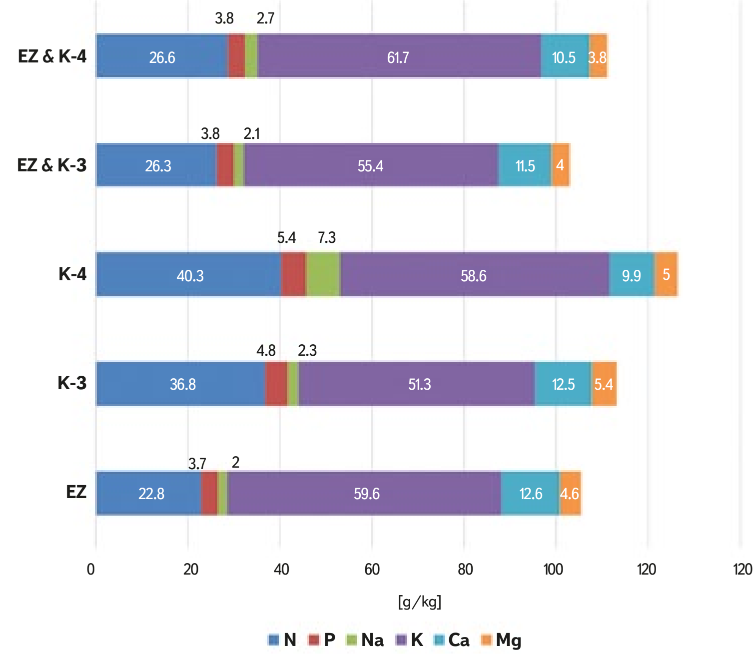

Fig. 7. Average content of nutrients in lettuce heads grown within the second-year pot experiment in g/kg of fresh biomass

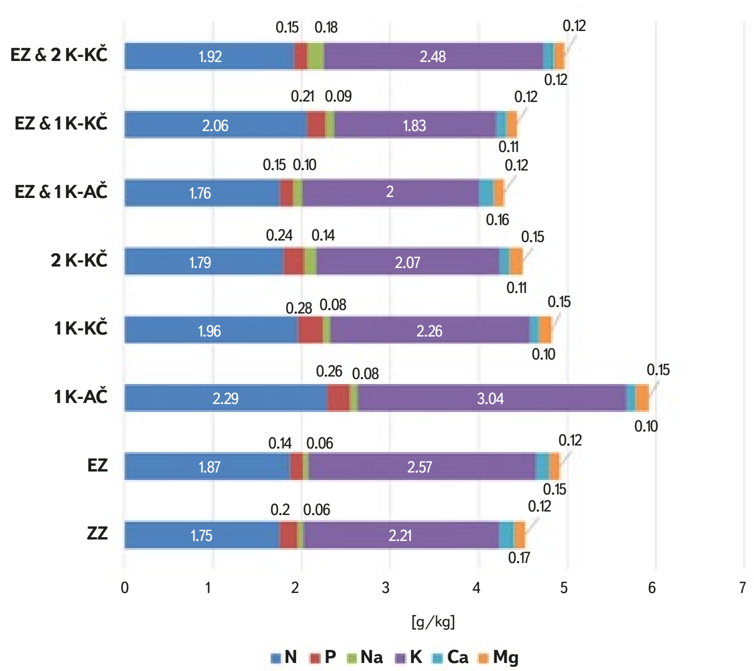

Fig. 6. Average content of selected nutrients in tomatoes grown within the first-year pot experiment in g/kg of fresh biomass

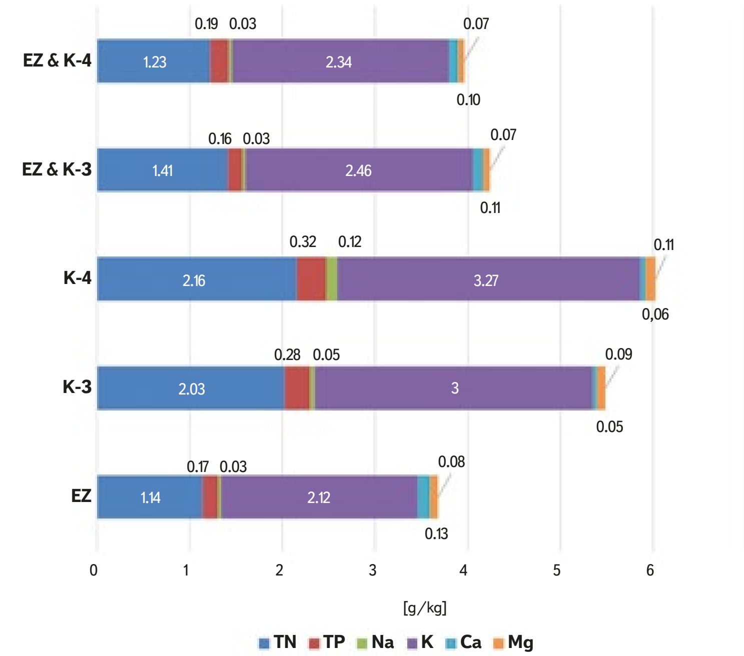

Fig. 8. Average content of selected nutrients in tomatoes grown within the second-year pot experiment in g/kg of fresh biomass

The content of nutrients in the leaves from heads of lettuce (*Figs. 5* and *7*) and also in the tomato fruits (*Figs. 6* and *8*) was comparable in both pot experiments. The contents of selected nutrients differ between the biomass of heads of lettuce and the biomass of fruits from tomato plants in total numbers mainly because both biomasses have very different dry matter. In the case of lettuce biomass, the dry matter is around an average value of 91 %, in the case of tomato biomass around an average value of 8 % (7 to 11 %). The differences in nutrient content in lettuce and tomato biomass from containers with individual substrates can be seen from the graphs in *Figs. 5–8*. Due to the conversion to fresh mass, the differences (e.g. in N and K content) are higher in lettuce biomass. The use of substrates from composting resulted in a demonstrably higher content of P, Na and, conversely, a lower content of Ca in tomato fruits in the case of using compost as an admixture. In the pot experiment in the second year, this difference was found only in clean substrates from composting. This was also related to the increase in N content in the biomass (*Fig. 8*). Similarly, a significantly higher content of all elements with the exception of Ca (a decrease in its content) was found in lettuce biomass from the pot experiment in the second year (*Fig. 7*).

Content of risk elements in useful parts of crops

The assessment was carried out for the following heavy metals and elements: Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn. The analytical procedure for determining the content in biomass and conversion to evaluable results for fresh matter was the same as in the case of the elements listed in the previous sub-chapter.

These results were compared with the limit contents established in the following regulations:

1. Commission Regulation (EC) No. 1881/2006 (hereinafter referred to as the "Regulation") setting limits of 0.2 mg/kg Cd, 0.3 mg/kg Pb.

2. National regulation Decree No. 53/2002 Coll. (hereinafter referred to as the "Decree"), setting limits (in mg/kg of fresh matter): 0.5 As, 0.2 Cd, 0.2 Cr, 10 Cu, 50 Fe, 0.03 Hg, 2.5 Ni, 0.3 Pb, 25 Zn. The Decree was repealed due to accession to the European Community on 1st August 2004. However, it still allows to assess and compare the level of contamination for more metals than the Commission Regulation, where limits are set only for Cd and Pb.

For tomato fruits, no exceedance of the limit values given by the Regulation for either Cd or Pb was detected for individual plants, in both pot experiments. Also, it was not detected that the older, no longer valid limits given by the Decree were exceeded for any monitored element. A comparison of the average values for individual substrate variants (*Tab. 1* and *2*) shows that no limit contents of risk elements were exceeded either. In tomato fruits, a statistically significant difference in content was found for Zn, Cu, and Cr (both pot experiments), for Ni, Mn, and Cd (pot experiment from the second year), and for Al (pot experiment from the first year).

An analysis comparing only container fills consisting entirely of soil or composts determined a statistically significant difference in content for Cd (pot experiment from the second year) and for Al, As, and Zn (pot experiment from the first year). However, in the case of the analysis for the first-year experiment, the analysis was affected by the size of the variance of the two values from the crop pairs, with the mean values lying close to each other.

Limit values were exceeded for lettuce leaves in all leaf samples for Cd from the second-year pot experiment and in all samples from the first-year pot experiment, with the exception of containers filled with K-AČ compost and K-KČ compost. The exceedance was valid for samples from all input soils. It was probably caused by the loading of these soils with Cd. When evaluating according to the limits from the Decree, an exceedance was determined in both pot experiments for Zn, Fe, Cr, and from the samples of the second year also in several cases for Ni and Hg. In the case of Hg, these were samples from containers using K-4 compost in mixtures. In the case of Ni, these were two samples out of three from a set of containers with input soil and two samples out of three containers with a mixture of input soil and K-4 compost. In contrast to the experiment from the second year, two samples of the experiment from the first year were determined to exceed the limit value for Cu and Hg. However, it was always only one sample from a pair. It cannot therefore be concluded that some substrate mixtures showed a higher transfer of the given elements to the leaves. In the case of a comparison of average values from individual substrate variants (*Tabs. 3* and *4*), it follows that the limit contents of Cr and Zn were exceeded in all substrate variants. Ni exceeded the average values for eroded soil and the mixture of eroded soil and K-4 compost from the second-year experiment. Overall, the most problematic was the occurrence of Cd values above the limit. In this case, the limit value in the leaves was already exceeded for the input soils in both experiments. This was also reflected in exceeding the limit value for mixtures of soil and compost. Paradoxically, in the case of 100% compost substrates, the average Cd contents were below the limit in four out of five cases. Therefore, it is not possible to unequivocally prove the negative effect of the application of composted sludge. Of the other risk elements with limits, Pb, Cu, As proved to be unproblematic.

A statistically significant difference in content was found in lettuce leaves for Cd and Mn (both pot experiments), Cu (pot experiment from the first year) and Hg with Zn (pot experiment from the second year). An analysis comparing only container fills consisting of 100 % soil or composts determined a statistically significant difference in content for Zn (both pot experiments) and Cd and Mn (pot experiment from the second year).

Tab. 3. Average values of heavy metals and arsenic in lettuce grown in the first year pot experiment (in mg/kg of fresh matter)

Soil/mixture	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
ZZ	204	0.181	0.883	0.801	3.88	215	0.032	37.5	1.57	0.090	48.0
EZ	120	0.138	0.431	0.268	5.80	127	0.019	30.7	1.30	0.069	50.5
1 K-AČ	90.1	0.180	0.126	0.487	9.41	123	0.018	4.51	1.89	0.090	107
1 K-KČ	156	0.181	0.398	0.680	7.75	161	0.021	18.4	1.30	0.091	193
2 K-KČ	105	0.180	0.207	0.446	7.97	185	0.010	4.51	0.70	0.090	151
EZ & 1 K-AČ	185	0.182	0.337	0.570	6.85	159	0.012	28.1	2.13	0.091	92.9
EZ & 1 K-KČ	116	0.184	0.197	0.463	7.59	139	0.014	12.2	0.67	0.092	66.2
EZ & 2 K-KČ	189	0.184	0.460	0.534	5.74	200	0.012	29.8	1.34	0.092	88.9
Limit values NK 1881/2006			*0.200*							*0.300*	
Limit values Decree 53/2002		*0.500*	*0.200*	*0.200*	*10.00*	*50*	*0.030*		*2.50*	*0.300*	*25.0*

Tab. 4. Average values of heavy metals and arsenic in lettuce grown in the second year pot experiment (in mg/kg of fresh matter)

Soil/mixture	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
EZ	153	0.182	0.758	0.677	6.40	144	0.022	52.4	2.84	0.091	41.6
K-3	228	0.179	0.150	0.753	6.88	246	0.015	20.7	1.90	0.090	83.4
K-4	147	0.180	0.163	0.613	6.87	165	0.040	32.0	1.81	0.090	77.2
EZ & K-3	132	0.183	0.658	0.627	6.77	134	0.069	37.8	1.89	0.128	42.2
EZ & K-4	215	0.181	0.715	0.764	8.45	301	0.036	44.6	4.43	0.090	74.4
Limit values NK 1881/2006			*0.200*							*0.300*	
Limit values Decree 53/2002		*0.500*	*0.200*	*0.200*	*10.00*	*50*	*0.030*		*2.50*	*0.300*	*25.0*

The results from the pot experiments can be compared with the results of a number of similar studies and experiments that have been carried out in practically all parts of the world. The aim of these studies and experiments is to verify the possibility of replacing substrates from peat and other non-renewable sources with substrates from composting, including composts used recycle sewage sludge. In the study [22], the authors conducted a pot experiment to investigate the effect of composted sewage sludge (KKOV) applied alone and mixed with chemical fertilizer on the growth and accumulation of heavy metals in lettuce grown on two soils (Xanthi-Udic Ferralosol and Typic Purpli-Udic Cambosol). The experiment included a control (fertilizer containing N, P and K); a composted sludge applied at a rate of 27.54 (KKOV), 82.62 (3KKOV), 165.24 (6KKOV) t/ha; and a mixture of composted sludge and chemical fertilizer (1/2 KKOV + 1/2 NPK). Application doses were determined according to local recommended doses. Application of KKOV increased biomass; content of Cu, Zn, and Pb in lettuce; total metals and metals extracted with DTPA in soil. KKOV at doses of 27.54 and 82.62 t/ha increases plant biomass less than NPK fertilizer alone.

Another study [32] was conducted with the aim of evaluating the potential possibility of using composted sewage sludge (KKOV) as an alternative to expensive peat (PE) for the cultivation of lettuce (*Lactuca sativa* L.). Five substrates were prepared with different percentages of KKOV and PE in the growth medium. The percentage of KKOV addition to PE was 0 %, 15 %, 30 %, 50 %, and 70 %. The growth media KKOV + PE had very good physical and chemical properties and significant content of plant nutrients, especially P, K, Ca, and Mg. The greatest growth increments and yields were achieved in the growth medium with 30% KKOV and 70% PE from the total volume. Shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight obtained from the growth medium with 30% KKOV and 70% PE were increased by 56.53 %, 43.93 %, 29.46 %, and 67.24 % in comparison with peat substrate. The addition of KKOV as a component of the growth medium increased the concentrations of nutrients (N, P, K, Mg, Ca, Cu, Mn, Zn, and Pb) in the lettuce plant. However, trace element levels in tissues were much lower than phytotoxic levels.

As part of the study [23], a greenhouse experiment was conducted with four lettuce cultivars comparing composted municipal waste with perlite (MSWC + P), composted sludge with perlite (KKOV + P), and peat with perlite (peat + P). Plant biometric parameters measured after 72 days of growth showed that the yield of plants cultivated on KKOV + P was similar to control plants, independent of the cultivar. In contrast, the MSWC + P mixture generally suppressed the formation of biomass, especially in the *Murai* and *Patagonia* cultivars. Compared to the peat + P mixture, both compost substrates reduced the accumulation of heavy metals in leaves, with a large effect in the *Maximus* cultivar. The amounts of Cd and Pb in the edible part were always below the limits set by European regulations.

The authors of the research published in the study [34] prepared a field test in which they grew tomatoes on soil enriched with sludge, soil fertilized with NPK fertilizer, and untreated soil. On soils enriched with the addition of sludge, a higher amount of Cd contained in the above-ground part of tomatoes was found compared to soil with inorganic fertilization. The Cd accumulation in the fruits was low compared to the other analysed plant parts and did not obviously differ depending on the type of soil. The amount of Cd in tomato fruits was an order of magnitude lower than in leaves.

The availability of metals and their accumulation in tomatoes with increasing addition of sludge to the soil was the subject of a study published in the paper of Elloumi et al. [35]. Results showed that soil pH decreased, while salinity, organic C, total N, available P, and reactive forms of Na, Ca, K, and heavy metals increased significantly with increasing sludge application rates. Of the three heavy metals Zn, Cu and Cr, Zn had the greatest ability to transfer from soil to plants. Low translocation of metals from roots to leaves was observed. The use of a dose of 2.5 to 5 % of sewage sludge appeared in the experiment as an effective and cost-effective method for restoring soil fertility.

Zhou et al. [36] found distinct differences in heavy metal concentrations in the edible parts of various vegetables grown in soil contaminated with heavy metals (Pb, Cd, Cu, Zn, and As). Heavy metal concentrations decreased as follows: leafy vegetables > stem vegetables/root vegetables/fruit vegetables > leguminous vegetables/melon vegetables. The ability of leafy vegetables to absorb and accumulate heavy metals was the highest and that of melon vegetables was the lowest.

The mentioned studies will make it possible to assess the risks in the use of substrates from composting sewage sludge from the point of view of the content of risk elements, especially heavy metals, which was also the subject of our experiments. Due to the accumulation of these elements in soils and in biomass during the transfer from sludge to compost, it is necessary to find suitable application doses of substrates that ensure compliance with limit values in soils and biomass, as well as limit the possible risk of phytotoxicity. A study focused on horticultural substrates [29] worked with a dose of composted sludge of only 2 kg of compost with sewage sludge of 2 to 4 kg per 1 m^2, which had a positive effect on soil properties and nutrient supply for cultivated vegetables. In our experiments, we verified the benefits and risks of doses of 8 kg of 100% compost per 1 m^2, when the risks were below the limit when used for growing tomatoes. In contrast, the use of similar substrates for leafy vegetables appears inappropriate.

In addition to the risks caused by the content of the studied heavy metals and arsenic, it is not possible to ignore the risks associated with the occurrence of other foreign substances and micropollutants in sewage sludge. In the paper [16], our research team presents an overview of drug residues and other micropollutants in sludge before and after composting. It is obvious that, for many of these substances, composting means their reduction or elimination. Styszko et al. [37] monitored changes in the content of selected drugs in sludge during their processing with the aim of safe use. In addition to composting, other methods of processing sludge for substrates usable in agriculture and reclamation are being studied, for example in the form of biochar preparation (e.g. [38, 39]). With the correct dosage, these procedures appear to be promising both from the point of view of eliminating a number of foreign substances (using thermal processes) and from the point of view of enriching the soil with organic matter and nutrients with gradual release.

CONCLUSION

The presented study was focused on checking the possible benefits and risks associated with the use of sludge from domestic and small WWTPs of two main technologies (activation WWTP, reed bed WWTP) within the local circular economy as a source of nutrients for growing selected crops after their processing by composting, which simulated domestic and community small-scale composting conditions. The aim was to verify the possible effects and thus provide information for decision-making in the process of dealing with this sludge. The predominant process is the transfer of sludge to a larger WWTP with sludge management. The study was also carried out with regard to the increasing number of questions about the possibilities of local composting of this sludge and the subsequent use of composts.

Literature reviews of similar studies show that the use of composts to improve soil properties, including composts that include sludge from municipal wastewater treatment, contributes to the support of yields of crops and trees, including various types of vegetables. At appropriate doses, there is no transfer of risk elements to these crops, or only to an extent that complies with the regulations. Both of the presented pot experiments confirmed these assumptions for tomatoes; however, in the case of growing lettuce, the content of some risk elements in the biomass was found to be exceeded. However, this was also influenced by the load on the used soils. The results thus show that local composting with the inclusion of sludge can theoretically achieve quality products that can be used in growing plants, but for selected groups of vegetables it is not suitable (e.g. for leafy vegetables such as lettuce) and excessive contamination of the consumed parts can occur.

The study yielded findings from which it is possible to set appropriate conditions and limits for the use of composts with the addition of sludge from the mentioned groups of WWTPs, considering the content and transfer of risk elements. Microbiological contamination was not monitored as the input analysis of the composts did not show above-limit contamination, or it was zero for most of the composts used. For practical use, however, it would be necessary to conduct a study of the content and transfer of other groups of pollutants, such as drug residues and microplastics.

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References

[1] KELESSIDIS, A., STASINAKIS, A. S. Comparative Study of the Methods Used for Treatment and Final Disposal of Sewage Sludge in European Countries. *Waste Management*. 2017, 32, pp. 1 186–1 195. Available at: https://doi.org/10.1016/j.wasman.2012.01.012

[2] HUDCOVÁ, H., VYMAZAL, J., ROZKOŠNÝ, M. Present Restrictions of Sewage Sludge Application in Agriculture within the European Union. *Soil & Water Research*. 2019, 14(2), pp. 104–120. Available at: https://doi.org/10.17221/36/2018-SWR

[3] SINGH, R. P., AGRAWAL, M. Potential Benefits and Risks of Land Application of Sewage Sludge. *Waste Management*. 2008, 28(2), pp. 347–358. Available at: https://doi.org/10.1016/j.wasman.2006.12.010

[4] NIELSEN, S., WILLOUGHBY, N. Sludge Treatment and Treatment Wetlands Systems in Danmark. *Water and Environmental Journal*. 2005, 19(4), pp. 296–305.

[5] UGGETTI, E., FERRER, I., LLORENS, E., GÜELL, D., GARCÍA, J. Properties of Biosolids from Sludge Treatment Wetlands for Land Application. In: VYMAZAL, J. (ed.). *Water and Nutrient Management in Natural and Constructed Wetlands*. Springer, 2010, pp. 9–20, ISBN 978-90-481-9584-8.

[6] LIU Y., MA, L., LI, Y., ZHENG, L. Evolution of Heavy Metal Speciation during the Aerobic Composting of Sewage Sludge. *Chemosphere*. 2007, 67(5), pp. 1 025–1 032. Available at: https://doi.org/10.1016/j.chemosphere.2006.10.056

[7] ATIYEH, R. M. et al. Effects of Vermicomposts and Composts on Plant Growth in Horticultural Container Media and Soil. *Pedobiologia*. 2000, 44(5), pp. 579–590. Available at: https://doi.org/10.1078/S0031-4056(04)70073-6

[8] OLESZKIEWICZ, J. A., MAVINIC, D. S. Wastewater Biosolids: An Overview of Processing, Treatment and Management. *Canadian Journal of Civil Engineering*. 2001, 28(S1), pp. 102–114.

[9] SULLIVAN, D. M. et al. Food Waste Effects on Fertilizer Nitrogen Efficiency, Available Nitrogen, and Tall Fescue Yield. *Soil Science Society of America Journal*. 2002, 66(1), pp. 154–161.

[10] BERTRAN, E., SORT, X., SOLIVA, M., TRILLAS, I. Composting Winery Waste: Sludges and Grape Stalks. *Bioresource Technology*. 2004, 95(2), pp. 203–208. Available at: https://doi.org/10.1016/j.biortech.2003.07.012

[11] CAI, Q.-Y., MO, C.-H., WU, Q.-T., ZENG, Q.-Y., KATSOYIANNIS, A. Concentration and Speciation of Heavy Metals in Six Different Sewage Sludge-Composts. *Journal of Hazardous Materials*. 2007, 147(3), pp. 1 063–1 072. Available at: https://doi.org/10.1016/j.jhazmat.2007.01.142

[12] CESARO, A., BELGIORNO, V., GUIDA, M. Compost from Organic Solid Waste: Quality Assessment and European Regulations for Its Sustainable Use. *Resources, Conservation and Recycling*. 2015, 94, pp. 72–79. Available at: https://doi.org/10.1016/j.resconrec.2014.11.003

[13] VACA, R. et al. Effects of Sewage Sludge and Sewage Sludge Compost Amendment on Soil Properties and Zea Mays L. Plants (Heavy Metals, Quality and Productivity). *Revista Internacional de Contaminación Ambiental*. 2011, 27(4), pp. 303–311. Available at: https://www.researchgate.net/publication/258210098_Effects_of_sewage_sludge_and_sewage_sludge_compost_amendment_on_soil_properties_and_Zea_mays_L_plants_heavy_metals_quality_and_productivity

[14] SMITH, S. R. A Critical Review of the Bioavailability and Impacts of Heavy Metals in Municipal Solid Waste Composts Compared to Sewage Sludge. *Environment International*. 2009, 35(1), pp. 142–156. Available at: https://doi.org/10.1016/j.envint.2008.06.009

[15] ROZKOŠNÝ, M., HUDCOVÁ, H., PLOTĚNÝ, M., NOVOTNÝ, R., MATYSÍKOVÁ, J. Kvalita kalů a odpadů z domovních a malých ČOV a možnosti jejich využití v zemědělství. *Vodohospodářské technicko-ekonomické informace*. 2015, 57(6), pp. 44–49. Available at: https://www.vtei.cz/2015/12/kvalita-kalu-a-odpadu-z-domovnich-a-malych-cov-a-moznosti-jejich-vyuziti-v-zemedelstvi/

[16] KRATINA, J., ROZKOŠNÝ, M., HUDCOVÁ, H., ŠEREŠ, M., HOLUBÍK, O. Studie přínosu extenzivní stabilizace čistírenských kalů z malých komunálních zdrojů pro jejich využití jako hnojiva. *Vodohospodářské technicko-ekonomické informace*. 2021, 63(6), pp. 23–33. Available at: https://www.vtei.cz/2021/12/studie-prinosu-extenzivni-stabilizace-cistirenskych-kalu-z-malych-komunalnich-zdroju-pro-jejich-vyuziti-jako-hnojiva/

[17] PLÍVA, P., JELÍNEK, A., HEJÁTKOVÁ, K. *Obecná podoba podnikové normy pro faremní kompost vyrobený kontrolovaným mikrobiálním procesem*. Biom.cz, 2002. [on-line] [accessed 17/06/18]. ISSN 1801-2655. Available at: http://biom.cz/cz/odborne-clanky/obecna-podoba-podnikove-normy-pro-faremnikompost-vyrobeny-kontrolovanym-mikrobialnim-procesem

[18] RAO, N., GRETHLEIN, H. E., REDDY, C. A. Effect of C/N Ratio and Moisture Content on the Composting of Poplar Wood. *Biotechnology Letters*. 1995, 17(8), pp. 889–892.

[19] ALIDADI, H., NAJAFPOOR, A. A., PARVARESH, A. Determination of Carbon/Nitrogen Ratio and Heavy Metals in Bulking Agents Used for Sewage Composting. *Pakistan Journal of Biological Sciences*. 2007, 10(22), pp. 4 180–4 182. Available at: https://scialert.net/abstract/?doi=pjbs.2007.4180.4182

[20] ROZKOŠNÝ, M., SEDLÁČEK, P., SOVA, J., FUNKOVÁ, R. Dražovice Reed Beds and Stabilisation Pond Wastewater Treatment System: Long-Term Operation and Monitoring Results. *Water Practice & Technology*. 2011, 6(3), pp. 1–8. Available at: https://doi.org/10.2166/wpt.2011.051

[21] ZUBILLAGA, M. S., LAVADO, R. S. Heavy Metal Content in Lettuce Plants Grown on Biosolids Compost. *Compost Science and Utilization*. 2002, 10(4), pp. 363–367.

[22] ZHAO, X. L. et al. Growth and Heavy-Metal Uptake by Lettuce Grown in Soils Applied with Sewage Sludg Compost. *Communications in Soil Science and Plant Analysis*. 2012, 43(22), pp. 1 532–1 541.

[23] GATTULLO, C. E., MININNI, C., PARENTE, A., MONTESANO, F. F., ALLEGRETTA I., TERZANO, R. Effects of Municipal Solid Waste- and Sewage Sludge-Compost-Based Growing Media on the Yield and Heavy Metal Content of Four Lettuce Cultivars. *Environmental Science Pollution Research*. 2017, 24, pp. 25 406–25 415.

[24] FAO. *Food Agriculture Organization, Faostat*. [accessed May 10, 2018]. Available at: https://www.fao.org/faostat/en/#data

[25] MOREIRA, R., SOUSA, J. P., CANHOTO, C. Biological Testing of Digested Sewage Sludge and Derived Composts. *Bioresource Technology*. 2008, 99(17), pp. 8 382–8 389. Available at: https://doi.org/10.1016/j.biortech.2008.02.046

[26] JOZÍFKOVÁ, Z. *Využití kontaktních testů fytotoxicity při hodnocení vedlejších energetických produktů. Diplomová práce*. Brno: Brno Technical University, 2011 [accessed November 1, 2023]. Available at: http://hdl.handle.net/11012/5671

[27] HEJÁTKOVÁ, K. et al. *Kompostování přebytečné travní biomasy (Metodická pomůcka)*. ZERA, o. s., 2017. 80 pp. ISBN 80–903548–6–6.

[28] REICHLOVÁ, E., VÁŇA, J., JANOVSKÝ, J. Hodnocení testů zralosti kompostu. *Rostlinná výroba*. 1996, 42(2), pp. 79–82.

[29] CASADO-VELA, J. et al. Evaluation of Composted Sewage Sludge as Nutritional Source for Horticultural Soils. *Waste Management*. 2006, 26(9), pp. 946–952. Available at: https://doi.org/10.1016/j.wasman.2005.07.016

[30] SAVEYN, H., EDER P. *End-of-Waste Criteria for Biodegradable Waste Subjected to Biological Treatment (Compost & Digestate): Technical Proposals*. European Commission EUR 26425 – Joint Research Centre – Institute for Prospective Technological Studies. EUR – Scientific and Technical Research Series, 2014. ISSN 1831-9424 (on-line). Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC87124

[31] ČSN 46 5735. *Kompostování*. Prague: Czech Office for Standards, 2020.

[32] DI SALVATORE, M., CARAFA, A. M., CARRATÙ, G. Assessment of Heavy Metals Phytotoxicity Using Seed Germination and Root Elongation Tests: A Comparison of Two Growth Substrates. *Chemosphere*. 2008, 73(9), pp. 1 461–1 464. Available at: https://doi.org/10.1016/j.chemosphere.2008.07.061

[33] JAYASINGHE, G. Y. Composted Sewage Sludge as an Alternative Potting Media for Lettuce Cultivation. *Communications in Soil Science and Plant Analysis*. 2012, 43(22), pp. 2 878–2 887.

[34] MORAL, R., CORTÉS, A., GOMEZ, I., MATAIX-BENEYTO, J. Assessing Changes in Cd Phytoavailability to Tomato in Amended Calcareous Soils. *Bioresource Technology*. 2002, 85(1), pp. 63–68. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0960852402000688?via%3Dihub

[35] ELLOUMI, N., BELHAJ, D., JERBI, B., ZOUARI, M., KALLEL, M. Effects of Sewage Sludge on Bio-Accumulation of Heavy Metals in Tomato Seedlings. *Spanish Journal of Agricultural Research*. 2017, 14(4), e0807. Available at: https://www.researchgate.net/publication/310599123_Effects_of_sewage_sludge_on_bio-accumulation_of_heavy_metals_in_tomato_seedlings

[36] ZHOU, H. et al. Accumulation of Heavy Metals in Vegetable Species Planted in Contaminated Soils and the Health Risk Assessment. *International Journal of Environmental Research and Public Health*. 2016, 13(3), 289. Available at: https://www.mdpi.com/1660-4601/13/3/289

[37] STYSZKO, K. et al. The Impact of Sewage Sludge Processing on the Safety of Its Use. *Scientific Reports*. 2022, 12, 12227. Available at: https://doi.org/10.1038/s41598-022-16354-5

[38] MUSTAFA, A. et al. Food and Agricultural Wastes-Derived Biochars in Combination with Mineral Fertilizer as Sustainable Soil Amendments to Enhance Soil Microbiological Activity, Nutrient Cycling and Crop Production. *Frontiers in Plant Science*. 2022, 13, 1028101. Available at: https://doi.org/10.3389/fpls.2022.1028101

[39] RACLAVSKÁ, H. et al. Effect of Biochar Addition on the Improvement of the Quality Parameters of Compost Used for Land Reclamation. *Environmental Science and Pollution Research*. 2023, 30, pp. 8 563–8 581.

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First experience with measurement of phosphorus retention in the Lhotský stream using TASCC method

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Keywords: phosphorus — pollution budget models — retention measurement — headwaters — TASCC

ABSTRACT

Eutrophication of watercourses and reservoirs, specifically the enormous phosphorus load on water, has been the biggest problem for water management in the Czech Republic for several decades. Budget models are effective support for rational solution; apart from resources, they must include the river network characterization, i.e. the retention of phosphorus in streams. A direct method for measuring phosphorus retention in watercourses under well-defined conditions, i.e. a method providing generalizable retention parameters, is fundamentally lacking and it could significantly increase the accuracy of the current models. It seems that TASCC method (Tracer Additions for Spiraling Curve Characterization) has such potential. In this article, we describe its first application in the Czech Republic, namely in the experimental basin of the Lhotský stream (Benešov district). On October 10, 2021, we selected a 200 m long channelized section, into which we applied a mixture of NaCl and $NH_4H_2PO_4$ solutions. Using conductivity probes, we monitored the advancing wave at a flow rate of 2.3 l/s. In total, 20 samples were analysed for chlorides and phosphorus, and helped us to characterize three parameters of the nutrient spiralling. According to TASCC method (Covino et al. [16]), we calculated the uptake length ($S_{W\,amb}$ = 70.8 [m]); areal uptake (U_{amb} = 0.000000178 [mg/m^2.s]; and uptake velocity ($v_{f\,amb}$ = 0.00936 [mm/min]). The resulting values are suspiciously low compared to the literature and the causes of the deviations are considered in the article. One of the most probable circumstances is the vague definition of the "saturation concentration" that needs to be achieved with the dose. Undoubtedly the main advantages of TASCC method are simplicity, safety, and environmental friendliness. The aim of the paper is to evaluate the applicability of the promising TASCC method for water management in the Czech Republic.

INTRODUCTION

The eutrophication of aquatic ecosystems (i.e. rivers, lakes and seas) is still one of the most serious means of degradation; moreover, its intensity continues to deepen, both around the world and in the Czech Republic. We can use various examples to support this statement, whether it is the increasing extent of dead zones in the seas [1], including those where our rivers flow [2], the most comprehensive report on the state of water bodies for the whole country, or the most serious examples of ecological disasters in Dyje [3] below Nové Mlýny (41.6 tons of fish of 26 species from 10 to 250 cm died in the summer of 2022 due to the "export" of decades of unresolved eutrophication of the reservoir) or on the Oder [4] in Poland and Germany (officially 360 tons of fish, while expert estimates speak of 1,650 tons, not including millions of bivalves and gastropods; A. Szlauer-Lukaszewska, pers. comm.).

From the limnology point of view, the situation has been quite clear for more than half a century [5]. Despite the long-term warnings of expert authorities [6] and recent warnings of legal authorities [7], the so-called "top" officials and the so-called "responsible" agents of interest organizations have managed to eliminate effective efforts to limit the entry of phosphorus into waters. Unfortunately, the elimination of phosphorus itself from wastewater still does not take place to the desired extent, so this key biogenic element from the point of view of the evolution of life on the planet accumulates more and more in the sediments and, through mass blooms of cyanobacteria and algae, causes significant long-term damage to water reservoirs, bathing waters, and breeding ponds.

In a rationally functioning society, the basin budget model would constitute, in addition to general laws whose basic feature is enforceability, an optimal professional tool used by water management to achieve statutory goals. Such a model should compile a prioritized list of point resources requesting investment in such order and amount that costs are spent efficiently. And, of course, any model is only as good as its input data.

After many years of sampling representative sets and systematic surveys of entire basins, when, for reasons of efficiency, we concentrated on the most accurate measurement of the resources themselves (i.e. the inputs to the budget models), we gradually reached a stage where the biggest weakness of these models are the processes, namely retention. By the general term retention, we mean the sum of physical, chemical and biological processes, which are naturally different for stagnant and flowing water. And it is understandable that individual events experienced different depths of knowledge. While the retention of phosphorus in reservoirs is robustly generalized thanks to the many decades of efforts by limnologists [8], the retention of phosphorus in streams, however significant it may be (*Fig. 1*), is due to little knowledge of systematic values often only arbitrarily calculated, or in better cases parameterized only very homogeneously for large areas or hydrological extent.

At the same time, it is true that the cycle of phosphorus in lake and reservoir ecosystems has been studied since the beginning of limnology with regard to the then prevailing sources, i.e. "ensuring" chronic supply. On the other hand, the impact of phosphorus from occasional, albeit significant episodes without distinction (if it is an episode of erosion or sewer overflow during the rains) is much less studied, or quantification of episodes is much more difficult [9], let alone generalization. In river ecosystems, the dichotomy is similar, but the total amount of directly measured data is incomparably smaller. It can therefore be summarized at the outset that the weakest point of our budget models is currently the directly measured retention of phosphorus in streams, and episodic retention has received the least attention.

Since phosphorus (due to the absence of a gaseous state) is not "lost" anywhere in the river network, nor does it accumulate in the long term (unfortunately, from a functional point of view, we separated the floodplain meadows from the rivers); on the other hand, to start with, it is not a big mistake if its retention is "annulled" in the long run. However, we must not forget this assumption at the moment when in the model we confront, for example, annual data from operational monitoring with real relationships from the basin, or by in-situ measured concentrations. While sampling usually covers the proverbial 12 seconds per year and we hope for their problem-free extrapolation to 365 days, in the interim there are apparently multiple to orders of magnitude changes in temporal retention [10]. And while in stream models there is usually nothing real to remind us of this error in assumption, in backwaters (where significant phosphorus accumulation from such episodes eventually occurs) it is the cyanobacterial blooms that give clear feedback to our theoretical models. After all, the results of each model must be properly interpreted, which cannot be done other than through a responsible author who knows the real environment.

The above-mentioned state of knowledge of phosphorus retention in aquatic ecosystems is given, among other things, by historically available methods. Methods based on radionuclide tracers are very limited outside the laboratory due to health risks. The differential measurement of concentrations "at the beginning" and "at the end" of the examined part of the ecosystem therefore have dominated the methods for a long time. Only the formulation and development of the "River Continuum Concept" [11] and the "Nutrient Spiralling concept" [12] derived from it enabled the development of new methods based on observing the induced response of the entire ecosystem. At the beginning, radionuclides were still used [13], but before long, more sensitive procedures using non-conservative markers in addition to simple nutrients were developed. Regardless of the chemical nature of the substances, however, the first wave of new methods consisted of reaching plateau values, steady-state equilibrium, in the monitored section, and that for a non-negligible long time. Such an experiment provided only one unique value for a given section. A comparison of the results from different locations revealed a large range of the three determined spiraling metrics: uptake length (S_W), areal uptake (U), and uptake velocity (v_f). Therefore, a methodological refinement followed; during one measurement, the plateau concentration was gradually increased in several consecutive steps [14]. From this differentiated series of measurements, the parameters of the nutrient spiraling were extrapolated towards unaffected conditions with much higher accuracy. However, with such a procedure, the examined river section was exposed to such a high load in total that some authors doubted the reliability of the data obtained in this way for common ranges of background measurements [15].

In methodology, the latest innovation is thus TASCC method (Tracer Additions for Spiraling Curve Characterization) [16], where the response on a known section of the watercourse is induced only by a one-time addition (slug injection) of a mixture of enriching nutrients and a conservative marker. Unlike the previous methods, each sub-sample taken from the resulting wave is used to calculate one particular value, i.e. the derivation of three spiraling metrics (S_W, U a v_f); it does not only take place by interpolating two or three points (corresponding to two or three steady-state concentrations), but by calculating a regression line over a large set of points. Such a procedure not only leads to higher statistical reliability, but mainly to higher factual accuracy of the calculated spiraling parameters characterizing nutrient retention (in our case phosphorus retention).

In their work [16], Covino et al. consistently distinguish three groups of spiraling metrics, or three sub-levels of nutrient uptake (U), which are gradually calculated and derived using the given procedure (S_W a v_f): ambient uptake (U_{amb}) is the desired target quantity characterizing the river's own spiral in unaffected conditions, towards which all methods should aim; added nutrient uptake (U_{add}) is an artificially increased part of the uptake caused by the experimental addition of nutrients, i.e. an increase in uptake due to the induction itself; and finally, total uptake (U_{tot}) is the sum of both mentioned sub-components and the only value directly obtained by chemical analysis of samples taken. Unlike total uptake, the two partial values can only be derived mathematically.

Like any method, TASCC has its limitations; however, the main advantages include health safety (compared to isotopes) and significantly less burden on the studied ecosystem (compared to steady-state methods). Most of the few works in which it has been used so far [17–26] deal with nitrogen retention but show its applicability both on a wider range of watercourse sizes and on a larger geographical distribution.

In the Czech Republic, TASCC method has not yet been used, despite the fact that it offers considerable potential in refining budget models. The goal of our study is, therefore, the implementation of the method and assessment of its suitability for direct measurement of phosphorus retention in watercourses depending on predictable parameters. In the ideal case, we hope that the method will help us to achieve a good ecological status more effectively, or economically suppress the manifestations of eutrophication in our degraded water ecosystems through more reliable modelling of processes (i.e. retention in the hydrographic network).

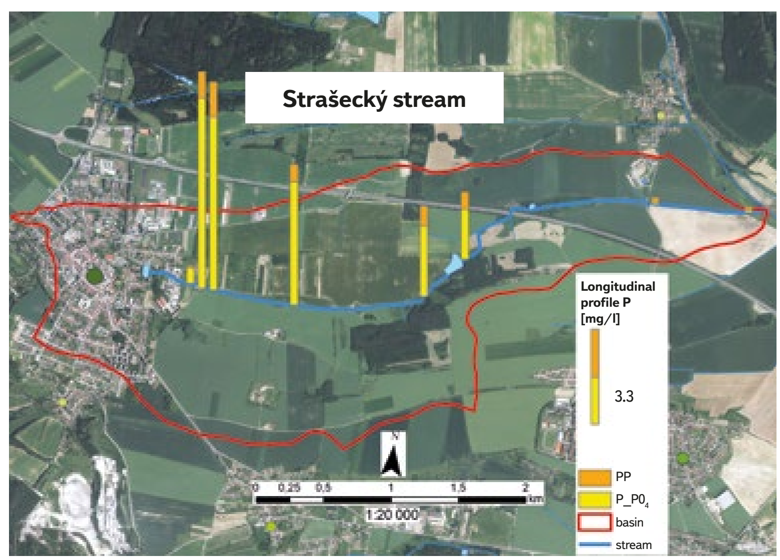

Fig. 1. An example of a significant change in phosphorus concentrations in the longitudinal profile downstream from Nové Strašecí (5,500 inhab.) on November 10, 2015, when 95 % of the flow in the Strašecký stream (5.0 km) consisted of WWTP discharge. Total phosphorus concentration decreased slightly from 7.4 mg/l in the WWTP outlet to 3.1 mg/l and 2.3 mg/l above and below Konopas pond, respectively, which was drained completely at the time. In the lower part of the stream, retention was significant and the concentration dropped to 0.210 mg/l at the confluence with Loděnice river. Particulate phosphorus (PP) is the difference between total and dissolved reactive phosphorus (PO_4-P)

METHODS AND LOCATION

The Lhotský stream (second order according to Strahler), originating 8 km east of Benešov, is a right-hand tributary of the Petroupimský stream, whose waters flow through the Benešovský stream near Čerčany into the Sázava river. The highest point of the catchment (2.6 km^2) is Kochánov hill (499 m above sea level), while the mouth (360 m above sea level) is only 1.46 km away. The predominant soil type is modal cambisol on a bedrock of heavily weathered granites. The catchment (*Fig. 2*) is dominated by arable land (82 %), with the minority occupied by forest (8 %) and permanent grassland (4 %). Due to the steepness of the land, the skeletal nature of the soils, ploughing, systematic drainage (29 %), and farming methods, the basin is regularly and long-term affected by severe erosion. The Lhotský stream (2.2 km) flows completely outside human settlements; therefore, the transported phosphorus (P) comes exclusively from non-point sources, and agricultural land has the decisive share of the P transfer.

In the closing part of the basin (GPS 49° 48’13.192”N; 14° 45’38.902”E), the stream flows through two morphologically different sections, which we used for research. In the upper section (hereafter called the canal), the stream is completely straightened, deepened with a bottom paved with solid concrete tiles. Apart from a solitary group of willow bushes, the steep banks are only covered with herbaceous ruderal vegetation (5–15 m), strongly overgrown with reeds at the lower end. On the other hand, in the lower section (hereafter called meanders) the stream meanders through an almost natural bed in a wider floodplain and is lined on both banks by a continuous strip of densely stratified tree and shrub vegetation (10–20 m). The riverbed is made up of different material, from boulders to coarse sand, depending on the prevailing velocities of the current. In both morphologically different parts of the riverbed, we defined two 200 m long experimental sections, which are separated only by a road culvert and about 20 m apart. Although we only used the channelized section for the initial measurement of P retention using TASCC method, we also monitored the same wave of water enriched with tracer mixture on the natural section of the meanders, albeit only through conductivity electrodes. From the measured conductivity curves, we derived the advance velocities on both sections. For the future comparison of the retention of two different types of bed, we therefore assume that the two sections do not differ either hydrologically or hydro-chemically, and the most significant difference in the investigated retention will be due to morphological differences.

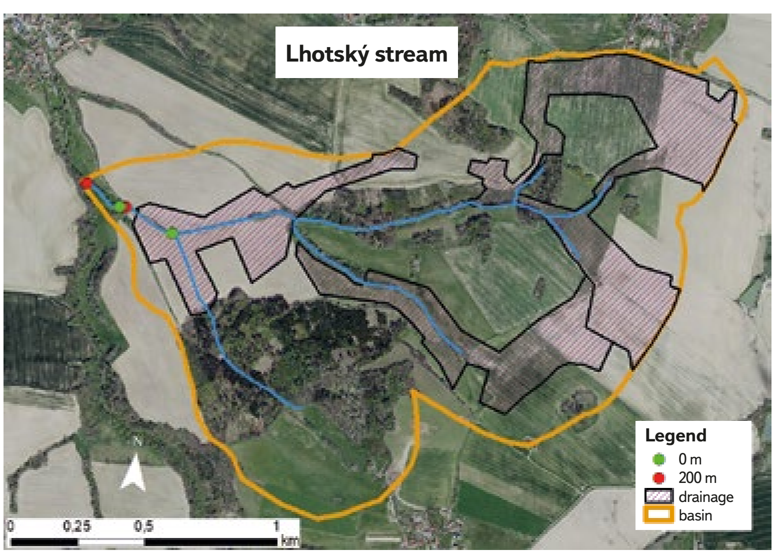

Fig. 2. Map of Lhotský stream showing both studied sections (200 m), where phosphorus retention was also measured by TASCC method (upper straightened section “canal”), or only arrival time and morphology of the riverbed (lower natural section “meanders”)

Based on the long-term monitoring of this site and for future comparison of the two sections, it is worth noting that, unlike the channelized section, the unpaved bed of the natural section is intensively reshaped cyclically by abundant episodes of high flows. During longer hydrological calm periods, fine sediments also settle in the riverbed, which, if accumulating for a longer period of time, form loamy to clayey benches. Due to the abundant supply of leaf litter and fallen branches that get caught in meanders and on boulders, a characteristic layer of sapropel is formed, gradually covered with a fine biofilm, in numerous stream pools on the surface of fine sediments. These structures are washed away with flush run-off, together with benthos. In contrast, due to high sun exposure, the thin biofilm in the upper section is formed by a characteristically solid coating of epilithic algae which, in addition to hydrological changes (scouring), is also subject to seasonal dynamics. As a result, in the meandering part of the stream there is usually a much larger area of active surfaces where retention can take place (both biological and physico-chemical).

For the initial measurement of phosphorus retention according to TASCC method [16], we added a mixture of a conservative component (NaCl), which serves as a marker easily detectable by a conductivity electrode, and a non-conservative component ($NH_4H_2PO_4$), whose retention is the subject of research, to the channelized section of the Lhotský stream. According to the method, we chose the amount of added phosphorus so that the maximum concentration at the end of the measured section reached the recommended “saturation” level. The saturation concentration is formally derived from enzymatic kinetics according to Michaelis-Menten, and therefore corresponds to the concentration at which the given reaction rate reaches its maximum. However, during the practical calculation of spiraling metrics in an anthropogenically unaffected and slightly affected watercourse, it is indicated that the dynamic concentration must be increased two to five times, at most ten times above the background concentration level [16, 19, 26]. To calculate it, it was necessary to measure the background value of the P concentration, determined as the concentration of dissolved orthophosphates (PO_4-P), and the flow rate (Q), but also the arrival time, i.e. the hydromorphological character of the watercourse. Since the last two characteristics essentially determine the course of the “flattening” of the concentration curve and depend mainly on the relative volume of the so-called dead zones (almost stagnant water in deep pools and hyporheal), which can be difficult to determine without prior measurement, we initially only roughly estimated both parameters.

In the autumn (October 21, 2021) we carried out an experimental measurement of phosphorus retention using TASCC method in the Lhotský stream. In the 200 m long section, marked “canal”, water flowed only over the surface of the concrete tiles (average width of the surface 74.8 cm); therefore, phosphorus retention was almost entirely caused by sorption to this minimal area and, to a limited extent, also by uptake of nutrients by a small amount of attached organisms. The only deviation from the uniform shape of the riverbed was one larger and two smaller bank scours with a total length of about 15 m, where the riverbed left the canal.

We placed three conductivity probes (HACH HQ 40d or WTW Multi 3320) on the measured section of the stream, enabling automatic data storage. The first was below the point of thorough mixing (0 m), the second in the middle of the section (100 m), and the third in the section closing profile (200 m). Using online conductivity measurements on the closing profile, we took a sequence of samples (wide-mouthed HDPE sample containers 0.5 l) covering the ascending and descending part of the conductivity wave, or the passage of changing concentrations and ratios of monitored nutrients and tracer. We arbitrarily changed the time interval between individual samples according to the rate of the changing conductivity; as a result, it ranged from 5 minutes to 30 seconds. We stopped sampling after the induced conductance had stabilized to the background value.

Samples for the analysis of nutrients and chlorides (PO_4-P, NH_4-N, Cl^-) and for basic chemical analysis (carried out within 24 hours in the accredited TGM WRI laboratory) were cooled with ice during transport. From the measured values,

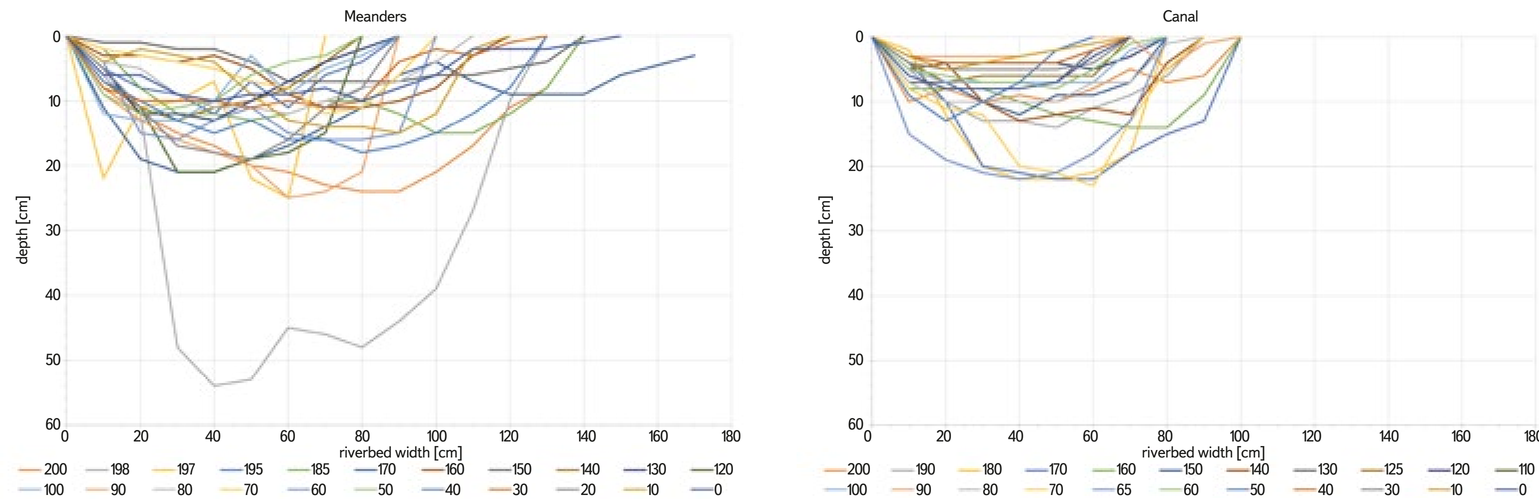

Fig. 3. Morphological differences of riverbed in the channelized (upper panel) and natural (lower panel) stretch of the Lhotský stream; the horizontal profile of the water depth and width was measured every 10 m from the beginning (0 m) to the end (200 m) of the studied section, more often in the case of significant changes

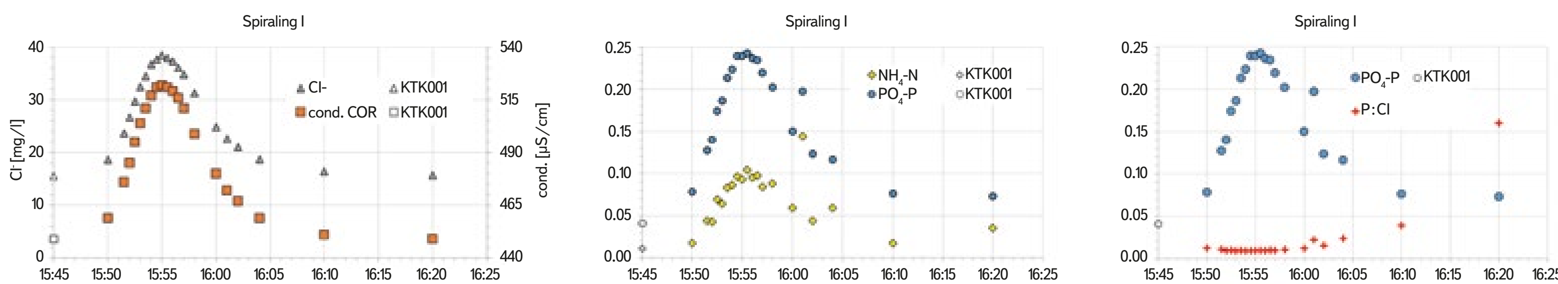

Fig. 4. Concentration of substances and conductivity on the closing profile of the straightened section (200 m) recorded in the passing wave (pouring of the mixture at 15:20) and compared to background values (KTK001)

i.e. changes in the ratio of phosphorus and chloride loss, or biologically active nutrient to conservative tracer, all three spiraling metrics were calculated in several mathematical steps (see equations 8–10 in Covino et al. 2010) according to TASCC method [16]. According to "Nutrient Spiralling Concept" [13], these are uptake length (S_W) [m], areal uptake (U) [$g.m^{-2}.s^{-1}$], and uptake velocity (v_f) [$m.s^{-1}$].

The uptake length (S_W) is a basic parameter indicating the theoretical distance for which the average nutrient atom is transported by the watercourse between two points of the bottom from the output (or release from the bottom) to its uptake (or binding to the bottom). Since the S_W is strongly influenced by the flow rate and velocity, or the water depth in the stream, outside of the retention process itself, it is appropriate (especially for the purpose of comparing different watercourses with each other or for comparing individual measurements carried out in the same watercourse, but under different hydrological conditions) to introduce a normalized quantity that converts these differences into a unit dimension. These quantities are areal uptake (U) and uptake velocity (v_f). While the areal uptake (U) indicates the total amount of nutrient received per unit time per unit area of a riverbed, the uptake velocity (v_f) corrects the uptake length to flow velocity and water depth (for details, see equations 8.6–8.10; interpretation and graphic manual in the methodological instructions [12]), thereby enabling mutual comparability of locations and periods of P retention measurement.

To calculate individual parameters of the spiral, we also measured the morphology of the flooded part of the canal (*Fig. 3*), i.e. the surface width (cross section every 10 m) and depth (every 10 cm on the given cross section) and calculated the wetted perimeter. All three parameters of the spiral, the so-called metric triad (see [12]) are mutually mathematically convertible quantities, and are thus in fact closely linked with each other. We derived the flow rate (the only quantity that unambiguously and reliably compares morphology of the channelized and natural stream section under current hydrological conditions) from the arrival time, i.e. from the interval between the maximum conductivity on the first (0 m) and the last profile (200 m). The flow rate (Q) was measured by the direct method on the gauging weir according to Cipoletti, ex post installed in the culvert, i.e. between the two sections. We consider the differences on the upper and lower edges of the examined section to be marginal. We measured Q only after the wave had passed, so that the hydraulic shock caused by the installation of the weir would not change the retention "capacities", i.e. the mechanical rearrangement of leaves, branches, and sediments.

RESULTS AND DISCUSSION

To measure the spiraling metrics, we used a mixture of NaCl solutions (conductivity = 25.0 mS/cm, 4 l) and $NH_4H_2PO_4$ (PO_4-P = 152 mg/l, 4 l). We poured the entire volume of the tracer solutions within five seconds onto a gravel chute just above the measured section to ensure thorough mixing while not stirring the sediment. We determined the loading according to the concentrations of NH_4-N and PO_4-P in the reference sample (0.019 and 0.024 mg/l) and the flow rate (2.4 l/s) determined the day before. Just before measurement, we took three control samples, namely at the beginning and end of the straightened section and at the end of the meander section. For the calculations of spiraling metrics, a sample from the upper edge of the experimental section (0.010 and

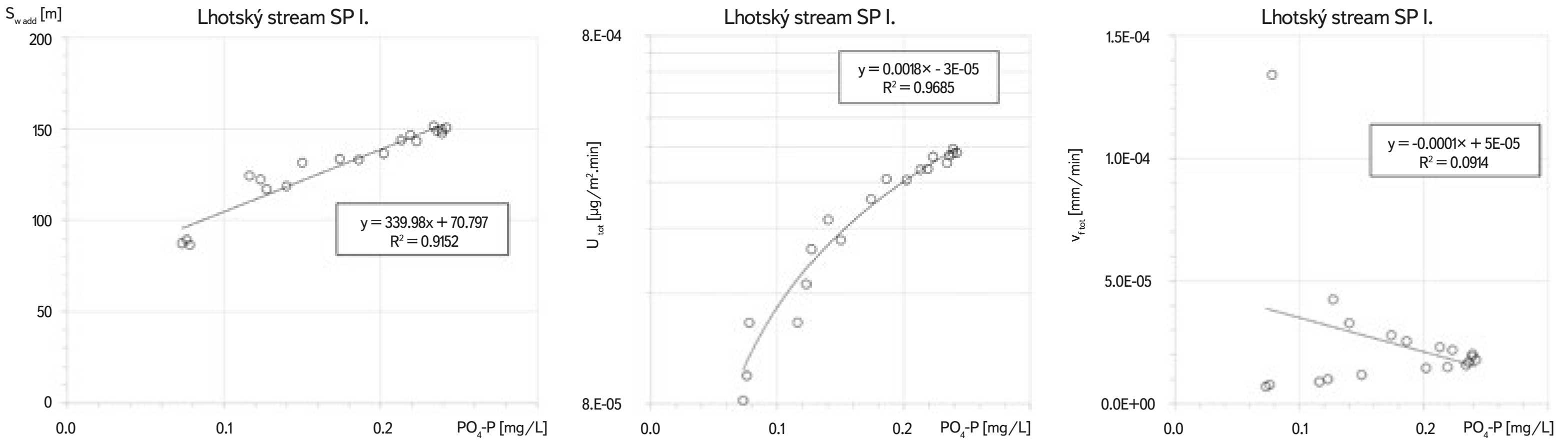

Fig. 5. Dynamic uptake length ($S_{W\text{-add}}$), total areal uptake (U_{tot}), and total uptake velocity ($v_{f\text{-tot}}$) of phosphorus values obtained by TASCC method in the channelized stretch of Lhotský stream

0.041 mg/l) was used as the background value of NH_4-N and PO_4-P; this is because the middle sample was contaminated by disturbed creatures moving in the riverbed. The phosphorus concentration of the sample taken in the third, lowest profile differed from the first by up to 5 %. From the values found during the wave passage (*Fig. 4*), it is clear that during the experiment there was an optimal increase in concentrations by the required two to five times stated in the literature [16, 19, 26].

At the current flow rate (2.3 l/s) and at a logging interval of 10–30 s, a flow velocity of 5.76 m/min (0.096 m/s) was measured. The resulting very fast wave passage (35 min from pouring, or from the wave passage through the 0 m profile to the collection of the last sample on the 200 m profile), we captured a total of 20 samples with the shortest interval of 30 s around maximum conductivity (*Fig. 4*). By synchronous measurement of conductivity in the lower section marked "meanders", we found a significantly lower flow velocity (3.60 m/min) given by the natural character of the riverbed and proving the preliminarily decisive influence of the watercourse hydromorphological status (*Fig. 3*) on the retention of P in the stream; this is because differences in the slope of the riverbed are minimal.

By integrating the concentration curve using the trapezoidal method, we found that the wave passage in the straightened section (200 m) resulted in retention of 353 mg of added phosphorus (38.8 %) and only 3.0 % of added chlorides. Subsequently, the total areal uptake is U = 0.714 [mg/m^2.s], whereby at the geometric mean of the background-corrected concentration (0.114 mg/l) we obtain the total uptake velocity v_f = 0.376 [mm/min]. Using the original methodology [16], by extrapolation for ambient condition we obtain the following spiraling metrics values: $S_{W\,amb}$ = 70.8 [m]; U_{amb} = 0.000000178 [mg/m^2.s] and $v_{f\,amb}$ = 0.00936 [mm/min], which are very low and practically zero for the last two quantities.

If we consider the coefficients of variance of the three calculated spiraling metrics (R^2 for S_W = 0.92, for U = 0.97, and for v_f = 0.13), it is also clear that the dependence of total absorption rate on concentration is insignificant while, in contrast, it is very high for the uptake length and the total areal uptake (*Fig. 5*). Although we did not observe any changes in flowing water during measurement (neither turbidity nor a change in the level), we were convinced by a random error of the extreme sensitivity of the correlation of partial uptake lengths (S_W) to the phosphorus concentration, or to small inaccuracies caused by sampling. When a sub-sample was taken at 4:01 p.m., fine sediment was probably stirred up because the measured concentrations deviate significantly from the otherwise smooth course. By subsequently omitting this outlier, the correlation coefficient improved dramatically (from the original value of R^2 = 0.73 to R^2 = 0.92).

A comparison with other works also shows that the most robust value – uptake length – is at the lower limit of observations at lightly polluted locations [26]; in other words, it is very short. Since the uptake length value (S_W) is strongly dependent on the actual flow (or current velocity and depth), the normalized values of areal uptake (U) and total uptake velocity (v_f) are used to compare the sites. However, the authors (who, as in our case, were faced with their atypical courses or values) make the fundamental assumption to explain the discrepancies, that the whole theory behind the calculation of the spiraling metrics is valid only in the range of conditions under saturation [25, 27], i.e. the addition of nutrients must significantly induce its uptake. In our case, this would mean (providing that we want to avoid the application of extreme doses) that the background values are too high in themselves. Such a claim, however, logically contradicts the detected short S_W. Therefore, in our opinion, another explanation is also possible, namely that the limited surface of the artificially channelized stream no longer has any additional capacity for P retention, and therefore the induction is not accompanied by the expected increase in retention. The last speculative cause of atypical values may be the apparent discrepancy in the ratio between phosphorus and chlorides in the so-called tailing of the concentration wave (*Fig. 4 below*), when the ratio P : Cl at the times of the last two samples (16:10 and 16:20) significantly increases. This increase apparently corresponds to a much slower stabilization of phosphorus concentration compared to the rapid return of chloride concentrations to background values. We call this possibility speculative because we have not yet gained enough experience with TASCC method to consider it reliably adopted.

Measurement of P retention by TASCC method only simulates conditions of balanced and low flow, which in our case is a range of up to about 10 l/s. Therefore, its results do not say anything about mutual relations at high flow rates or extreme loads. During torrents, one can theoretically consider a negligible proportion of the adhesion of erosion particles in the biofilm. However, this will be very limited by the spatially thin biofilm because the section is not saturated with nutrients from municipal pollution, and also by the short duration of the peaks. Moreover, scouring of the biofilm rather than its growth is likely to occur during these short episodes. A much higher retention capacity can be assumed in the lower, natural section of the Lhotský stream. Not only longer contact time between flowing water and the bed, but mainly the more developed hyporheal will probably multiply the resulting retention. We therefore believe that only further measurements comparing both sections and carried out in different seasons will provide a more comprehensive picture of the of the spiralling metrics, i.e. the phosphorus retention in an exclusively agricultural stream.

CONCLUSIONS

We consider made-up ground of the applied dose to be a critical feature of the not very widespread TASCC method; without prior measurement it is difficult to estimate the desired saturation concentration. On the other hand, even a simple inorganic salt in a small amount is pollution, and this results in the size and number limit of the measured flows. In any case, compared to methods using radionuclides, TASCC method is completely safe and, unlike methods using concentration plateaus, the total consumption of chemical substances is fractional (although it is definitely not negligible if the method is eventually expanded). Simplicity, safety, and environment friendliness are therefore the main advantages of this method. Only after resolving the ambiguities of the increase in the made-up ground can we proceed to comparison of sections in different hydromorphological conditions, and it will be possible to definitively expand its wider application in the conditions of the Czech Republic. We believe that TASCC method will bring a more precise and, above all, directly measured characterization of phosphorus retention in streams for the entire country, starting with average conditions, or balanced flows. Retention values determined in this way can significantly refine our budget models and therefore increase their credibility when discussing corrective measures.

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References

[1] BREITBURG, D., LEVIN, L. A., OSCHLIES, A., GRÉGOIRE, M., CHAVEZ, F. P., CONLEY, D. J., ZHANG, J. et al. Declining Oxygen in the Global Ocean and Coastal Waters. *Science*, 2018, 359, 6371.

[2] CARSTENSEN, J., CONLEY, D. J. Baltic Sea Hypoxia Takes Many Shapes and Sizes. *Limnology and Oceanography Bulletin*. 2019, 28(4), pp. 125–129.

[3] FIALA, D. *Masový úhyn ryb na Dyji v létě 2022 a sinice Aphanizomenon flosaque – příčiny a okolnosti*. Prague: T. G. Masaryk Water Research Institute, p. r. i., 2023, p. 82.

[4] FREE, G., VAN DE BUND, W., GAWLIK, B., VAN WIJK, L., WOOD, M., GUAGNINI, E., STIELSTRA, H et al. An EU Analysis of the Ecological Disaster in the Oder River of 2022: Lessons Learned and Research-Based Recommendations to Avoid Future Ecological Damage in EU Rivers, a Joint Analysis from DG ENV, JRC and the EEA. *Publications Office of the European Union*. 2023.

[5] DILLON, P. J., RIGLER, F. H. The Phosphorus-Chlorophyll Relationship in Lakes. *Limnology and Oceanography*. 1974, 19(5), pp. 767–776.

[6] HRBÁČEK, J. Jsou fosfáty hlavní příčinou eutrofizace jezer a přehradních nádrží? *Vesmír*. 1971, 50(4), p. 125.

[7] PUFAN, G., WELDON, P., RADULESCU, M., VANSILLIETTE, A., COLONERUS, M., GULLOVA, Z., PREISS, I. et al. *Water Quality in the Danube River Basin: Progress in Implementing the Water Framework Directive but Still Some Way to Go*. Luxembourg: European Court of Auditors, Union, P. O. O. T. E., 2016, p. 86.

[8] HEJZLAR, J., ŠÁMALOVÁ, K., BOERS, P., KRONVANG, B. Modelling Phosphorus Retention in Lakes and Reservoirs. *Water, Air, and Soil Pollution*. 2006, 6(5–6), pp. 487–494.

[9] ZNACHOR, P., ZAPOMELOVA, E., REHAKOVA, K., NEDOMA, J., SIMEK, K. The Effect of Extreme Rainfall on Summer Succession and Vertical Distribution of Phytoplankton in a Lacustrine Part of a Eutrophic Reservoir. *Aquatic Sciences*. 2008, 70(1), pp. 77–86.

[10] DURAS, J., MARCEL, M., KUBÍK, M., KOŽELUH, M., KOPP, J. Odlehčované odpadní vody – ošklivá stránka hezkých měst. In: KABELKOVÁ, I., BENÁKOVÁ, A., ŠPAČKOVÁ, A., BAREŠ, V. (eds.). *15. bienální konference CzWA 2023*. B. m.: Asociace pro vodu ČR, 2023, pp. 66–73.

[11] VANNOTE, R. L., MINSHALL, G. W., CUMMINS, K. W., SEDELL, J. R., CUSHING, C. E. River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences*. 1980, 37(1), pp. 130–137.

[12] WORKSHOP, S. S. Concepts and Methods for Assessing Solute Dynamics in Stream Ecosystems. *Journal of the North American Benthological Society*. 1990, 9(2), pp. 95–119.

[13] NEWBOLD, J. D., ELWOOD, J. W., O'NEILL, R. V., VAN WINKLE, W. Measuring Nutrient Spiralling in Streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 1981, 38(7), pp. 860–863.

[14] PAYN, R. A., WEBSTER, J. R., MULHOLLAND, P. J., VALETT, H. M., DODDS, W. K. Estimation of Stream Nutrient Uptake from Nutrient Addition Experiments. *Limnology and Oceanography: Methods*. 2005, 3(3), pp. 174–182.

[15] HALL, JR, R. O., BAKER, M. A., ROSI-MARSHALL, E. J., TANK, J. L., NEWBOLD, J. D. Solute-Specific Scaling of Inorganic Nitrogen and Phosphorus Uptake in Streams. *Biogeosciences*. 2013, 10(11), pp. 7 323–7 331.

[16] COVINO, T. P., MCGLYNN, B. L., MCNAMARA, R. A. Tracer Additions for Spiraling Curve Characterization (TASCC): Quantifying Stream Nutrient Uptake Kinetics from Ambient to Saturation. *Limnology and Oceanography: Methods*. 2010, 8(9), pp. 484–498.

[17] ARCE, M. I., VON SCHILLER, D., GOMEZ, R. Variation in Nitrate Uptake and Denitrification Rates across a Salinity Gradient in Mediterranean Semiarid Streams. *Aquatic Sciences*. 2014, 76(2), pp. 295–311.

[18] DIEMER, L. A., MCDOWELL, W. H., WYMORE, A. S., PROKUSHKIN, A. S. Nutrient Uptake along a Fire Gradient in Boreal Streams of Central Siberia. *Freshwater Science*. 2015, 34(4), pp. 1 443–1 456.

[19] RODRIGUEZ-CARDONA, B., WYMORE, A. S., MCDOWELL, W. H. DOC:NO_3- ratios and NO_3- Uptake in Forested Headwater Streams. *Journal of Geophysical Research-Biogeosciences*. 2016, 121(1), pp. 205–217.

[20] DAY, N. K., HALL, R. O. Ammonium Uptake Kinetics and Nitrification in Mountain Streams. *Freshwater Science*. 2017, 36(1), pp. 41–54.

[21] GARCÍA, V. J., GANTES, P., GIMÉNEZ, L., HEGOBURU, C., FERREIRO, N., SABATER, F., FEIJOÓ, C. High Nutrient Retention in Chronically Nutrient-Rich Lowland Streams. *Freshwater Science*. 2017, 36(1), pp. 26–40.

[22] COVINO, T. P., BERNHARDT, E. S., HEFFERNAN, J. B. Measuring and Interpreting Relationships between Nutrient Supply, Demand, and Limitation. *Freshwater Science*. 2018, 37(3), pp. 448–455.

[23] REINALDO FINKLER, N., TROMBONI, F., BOËCHAT, I. G., GÜCKER, B., GASPARINI FERNANDES CUNHA, D. Nitrogen and Phosphorus Uptake Dynamics in Tropical Cerrado Woodland Streams. *Water*. 2018, 10(8), 1080.

[24] SALTARELLI, W. A., DODDS, W. K., TROMBONI, F., CALIJURI, M. D. C., NERES-LIMA, V., JORDÃO, C. E., CUNHA, D. G. F. et al. Variation of Stream Metabolism along a Tropical Environmental Gradient: Stream Metabolism Variation. *Journal of Limnology*. 2018, 77(3).

[25] WEIGELHOFER, G., RAMIÃO, J. P., PURITSCHER, A., HEIN, T. How Do Chronic Nutrient Loading and the Duration of Nutrient Pulses Affect Nutrient Uptake in Headwater Streams? *Biogeochemistry*. 2018, 141(2), pp. 249–263.

[26] CUNHA, D. G. F., FINKLER, N. R., GÓMEZ, N., COCHERO, J., DONADELLI, J. L., SALTARELLI, W. A., THOMAS, S. A. et al. Agriculture Influences Ammonium and Soluble Reactive Phosphorus Retention in South American Headwater Streams. *Ecohydrology*. 2020, 13(2), e2184.

[27] WEIGELHOFER, G. The Potential of Agricultural Headwater Streams to Retain Soluble Reactive Phosphorus. *Hydrobiologia*. 2017, 793(1), pp. 149–160.

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Development of the RainWaterManager software tool

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Keywords: Rainwater management — climate change — ČSN 75 9010 — TNV 75 9011

ABSTRACT

Rainwater management is currently one of the frequently discussed topics in the further territorial development of towns and municipalities. The same question is also addressed in the context of climate change and its effect on already existing urban areas. Currently, the most common solution for the disposal of rainwater is its drainage using sewage systems. In connection with climate change, this concept of rainwater management is beginning to show its disadvantages. Rainwater is quickly drained away, which negatively affects moisture conditions in the urban landscape. The consequence of this is its drying and overheating. Another disadvantage is overloading of sewer networks during extreme rainfall events. The solution to eliminate these disadvantages can be an effort to retain the precipitation at the point of impact. However, this concept brings with it a number of questions: What measures can be used for this purpose? What are the spatial requirements for creating these measures? What is the price of their implementation? Can local government demand implementation of these measures by private investors? the answers to these questions are often not trivial and depend on the specific circumstances and the number of assessed criteria. Some help in this regard comes from the RainWaterManager software. This tool helps to choose appropriate measures for rainwater management, to estimate its effectiveness, spatial and economic requirements, and shows how their implementation can be promoted.

INTRODUCTION

In large cities around the world, various adaptation measures have been proposed for a long time, one of which is to improve rainwater management [1, 2]. The current concept still relies heavily on it being diverted from the point of impact. For this, unified or partitioned sewage systems are usually used. The shortcomings of this solution are overloading of sewer networks and the negative influence of moisture conditions at the point of precipitation impact [3]. Overloading of sewer networks occurs in particular in cases of extreme rainfall. Subsequently, the absence of moisture in the soil profile, caused by the rapid drainage of water, negatively affects urban greenery, reduces natural evaporation value, and thus contributes to the formation of heat islands and the overall deterioration of the urban microclimate. Due to the ever-increasing manifestations of climate change, it can be expected that the frequency of extreme precipitation totals and average temperatures will be increasing [4]. The answer to these problems could be a new system for rainwater management. The main philosophy of this system is the retention and use of rainwater at the point of impact. The promotion of these approaches in urban areas in the Czech Republic is currently at the stage of planning and implementation of initial projects. Due to the need to adapt to climate change, their application is supported in practice, but it often encounters technical, economic, legislative, and institutional difficulties [5, 6]. These semi-natural rainwater management measures (hereinafter referred to as RWM measures) are promoted under the name blue-green infrastructure (BGI), the purpose of which is to reduce the negative effects of climate change and increase the comfort of the urban environment for its inhabitants [7–9].

There are several types of RWM measures that can be used for rainwater management in the sense of the BGI concept. Primarily, these measures can be divided into five categories according to their function:

1. capture and use of water (stormwater tanks and its further use, e.g. irrigation),
2. surface retention (green roofs, permeable and semi-permeable surfaces),
3. linear and point infiltration (infiltration broad-base terraces, infiltration furrows, infiltration shafts, underground tanks with infiltration),
4. drainage of the area into a recipient (drainage ditches),
5. retention of water with regulated outflow (surface and underground reservoirs with regulated outflow, flood-release basins – polders, artificial wetlands).

The complete list of these measures is extensive and varied. Individual RWM measures differ from each other in the type of measure, effectiveness, and implementation and spatial requirements. It also includes measures that have been used for grey water management for a long time, introduced in the sense of green infrastructure development or their combination [7, 9, 10]. Their implementation is often associated with new construction; however, they can also be added to already existing built-up area. The applicability of individual measures depends primarily on the physical and geographical conditions of the given site and the availability of suitable areas (especially in the case of an existing built-up area). A separate issue is the cost and the need for their operational maintenance. An important question arises for the investor – which measure to decide on?

METHODOLOGY AND MATERIAL

RWM software development

RainWaterManager (RWM) software was developed to support the user in the decision-making process on the choice of RWM measures. Primarily, the software is intended to help with selecting a suitable RWM measure, evaluating its effectiveness, and promoting its implementation. Secondly, it should raise awareness of their existence and use. A total of 17 RWM measures are included in the software (*flood-release basin; stormwater retention tank; underground retention tank; rain garden; green roofs; surface infiltration system; infiltration longitudinal features; concentric surface infiltration; infiltration tunnel; infiltration shaft; underground infiltration drain; rainwater accumulation; pool, wetland in an urbanized landscape; herb beds; green facades; planting trees and shrubs; water features*). Individual measures are described in detail in the catalogue of RWM measures [10]. The digital version of the RWM catalogue is part of the RWM software.

RWM software is divided into four separate modules. These are accessible through the splash window (*Fig. 1*). The individual modules are:

- „Measure selection"
- „Measure dimensioning"
- „Enforcement tools"
- „Catalogue of measures"

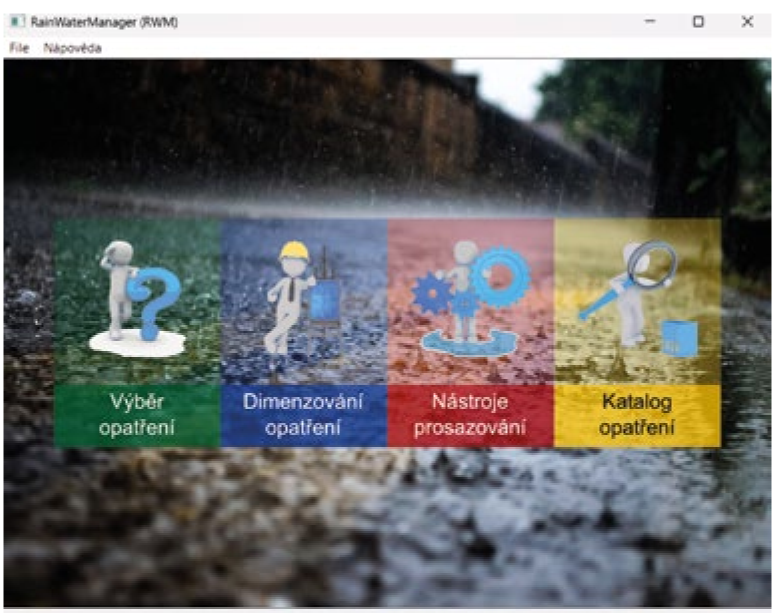

Fig. 1. RWM software splash window

„Measure selection"

This module helps the user to choose the appropriate RWM measure. The user chooses preset answers to 11 questions. The questions cover a wide range of areas including thematic focus, use of space, natural conditions, local restrictions, and costs of implementation and maintenance. There are a total of 38 possible answers. The answers are used as input criteria for evaluating the appropriateness of measures. Multi-criteria analysis (MCA) is used for this evaluation [11, 12]. In the MCA process, all RWM measures available in the RWM software are evaluated. Based on the choice of a specific criterion, all RWM measures are scored. The degree of scoring depends on the degree of appropriateness of the given measure for the chosen criterion. If the chosen criterion fully corresponds to the needs of the given measure, it is evaluated with a full number of points. In other cases, the measure is evaluated with fewer points depending on the degree of correspondence. A point scale of 1–5 is used for the assessment (1 – the least, 5 – the most). With each addition of another criterion, each measure is assigned a relevant number of points. The measure that thus receives the highest point evaluation is selected as the most appropriate. The point values of the relationships between criteria and measures are defined in a preference matrix. This matrix has been preset to achieve maximum objectivity. However, the user can modify the preference matrix and thereby inject their own preferences into the MCA process.

MCA results are shown both graphically and numerically. Each measure is assigned a pictogram within the RWM. Pictograms are sorted in descending order based on the achieved point score from the MCA. The relative value of the score (max. 100 %) is shown under the relevant pictogram. The presentation of MCA results in the „Measure selection" window is shown in *Fig. 2*. After clicking on the pictogram, the user is shown a detailed description of a specific RWM measure and its application in practice.

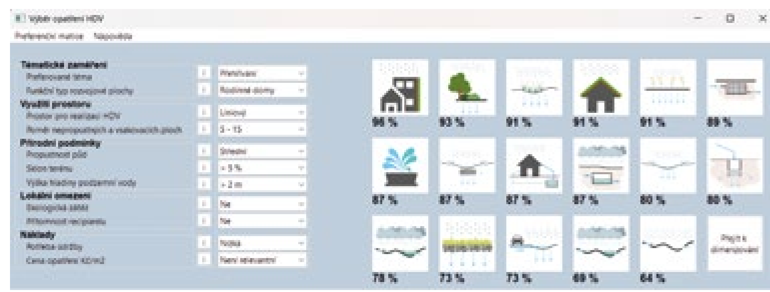

Fig. 2. Presentation of MCA results in the „Measure selection" module

„Measure dimensioning"

In this module, the user can simply calculate the values of selected hydrological characteristics in the area and the effect of the selected RWM measure on these values. The user can thus evaluate the necessary scope of the planned measure, its effectiveness, or price. The graphic form of the „Measure dimensioning" panel is shown in *Fig. 3*.

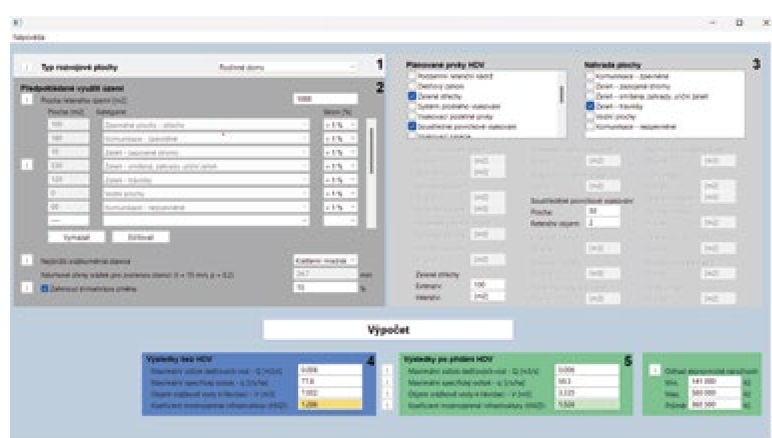

Fig. 3. Graphic form of the „Measure dimensioning" module

For the primary estimation of hydrological characteristics, it is necessary to enter a simplified description of the expected use of the site. The user enters the sizes of the individual areas that together form the area of interest, selects their type from the menu, and assigns them an inclination value. It is also necessary to indicate the amount of design rainfall. It is possible to enter the amount of rainfall manually (knowledge of the amount of precipitation for rain with a duration of t = 15 min and a repetition time of p = 0.2 for the given site is required), or use data from the nearest rain gauge station offered by the program. The calculation can also consider the expected influence of future climate change on the value of precipitation intensity [4, 13, 14]. The calculation itself is implemented based on the rational method [15]. The selected hydrological characteristics are the values of maximum stormwater runoff, maximum specific runoff, and volume of rainwater to be loaded. Furthermore, the blue-green infrastructure coefficient (BGIC) is calculated.

The type and extent of RWM measures that the user intends to implement can then be added to the primary estimate. It is also necessary to enter what type of area will be replaced by the measure. Subsequently, there is a new calculation, which takes into account the effect of RWM measures on selected hydrological characteristics. When selecting a RWM measure, the estimated cost of its implementation is also calculated.

„Enforcement tools"

The „Enforcement tools" module is primarily intended for the public administration representatives. It is an overview of tools that can be used to support and promote effective stormwater management in urban and municipal development sites. The individual tools are based on published general lists of tools and their specifications. They are categorized according to the hierarchical level of public administration, the subject concerned, and the phase of the process (planning, implementation, operation). The goal is to find the most suitable tool for the given situation. In total, 18 types of instruments are processed, divided into 5 categories (normative; conceptual; coordination and organizational; economic; voluntary and ethical) [16]. The MCA method [11, 12] is again used for tool selection. MCA criteria are determined based on the choice of answers (17 possible answers in total) to four initial questions. The presentation of the results is similar to the „Measure selection" module; it is also possible to go to the detail of the given tool by clicking on the pictogram. The graphic form of the „Enforcement tools" module is shown in *Fig. 4*.

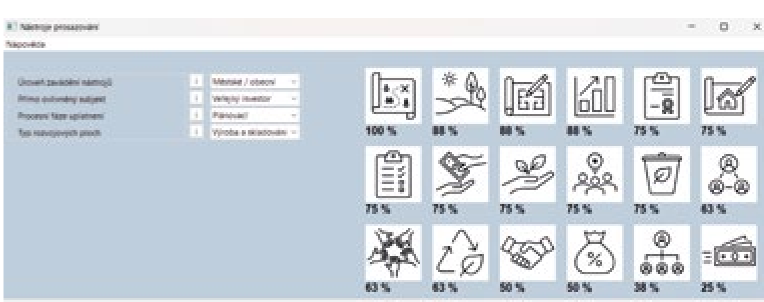

Fig. 4. Graphic form of the „Enforcement tools" module

„Catalogue of measures"

The software also includes a full-fledged digital version of the *Catalogue of Measures for Effective Rainwater Management on Development Areas of Urbanized Areas* [10]. The catalogue contains information about the project framework and its connection to the TA CR project *„SS03010080 – Interdisciplinary approaches to efficient rainwater management on development sites of urban areas in the economic, social and environmental context"*, the methodology of creating the catalogue, the catalogue of effective rainwater management elements, the catalogue of functional types of development sites, and the catalogue of tools for the promotion of effective rainwater management.

The RWM software is designed as a standalone application (*.exe) developed in the C++ programming language. It does not require an installation. The software is available in the form of a distribution package, which contains the RWM program and the attached documents to which reference is made (catalogue of RWM measures). The use of the software is not charged or otherwise restricted. The software can be found at: https://www.fzp.czu.cz/rwm

RESULTS

The RWM program serves to support decision-making in the area of stormwater management. The results it provides to the user also correspond to this. The „Measure selection" and „Enforcement tools" modules help the user in the decision-making process regarding the choice of the RWM measure itself, or finding a way for its enforcement in practice. These decisions are supported by detailed descriptions of individual measures (tools) supplemented by examples of their use in practice. Another type of results is offered by the „Measure dimensioning" module. Here, selected hydrological characteristics are estimated in a simplified manner without RWM measures and subsequently with their consideration. The user thus gets an idea of the effectiveness of the selected RWM measure. A price estimate for implementation is also calculated. Thanks to this, the user has the opportunity to compare the economic and functional efficiency between individual types of measures.

Other results are:

- Maximum rainwater runoff – indicates the maximum runoff (flow) of water (Q [m^3/s]) that flows out of the area after/during a precipitation event. The calculation is carried out using the rational method according to the ČSN 75 6101 standard.
- Specific runoff – q [l/s/ha] expresses how much water flows per unit of time from a unit area of the basin (sub-basin).
- Unprocessed volume of precipitation water – indicates the volume of water (V [m^3]) that will flow from the area after/during a precipitation event with a duration of 15 min. The calculation of this volume is based on the rational method (ČSN 75 6101).
- Blue-green infrastructure coefficient (BGIC) – evaluates the statistics of areas in terms of green ecosystem functions (e.g. microclimate, biodiversity, residential function) and natural water circulation functions (retention, infiltration, evaporation, and water purification).
- Estimate of economic demand – this is an indicative price for the implementation of the given RWM measures. The price is calculated as the unit price (CZK) for 1 m^2 (or 1 m^3) of the implementation of the given RWM measure, multiplied by the given number of units. In the case of selecting several measures, it is the sum of the prices for the implementation of individual measures.

DISCUSSION

The purpose of RWM software is not in any way to replace the design work associated with the proposals for rainwater management measures. It is primarily oriented towards raising awareness of the issue for small investors and public administration representatives. This is also reflected in the very concept of the software, which tries to simplify the given issue as much as possible, supplemented by a lot of explanatory information. RWM is intended to help these user groups raise awareness of the possibilities of using individual RWM measures and their influence on the hydrological situation in the area they manage. Users can thus obtain, for example, information about the extent of RWM measures that must be implemented so that there is no runoff from their property, or get an overview of the prices for the implementation of these measures. For public administration representatives, the „Enforcement tools" module further shows the ways in which the construction of these measures can be enforced within their municipality. However, this does not mean that RWM cannot be used, for example, by users from the ranks of civil engineers or designers. It offers these groups the possibility of a quick orientation assessment of individual RWM measures, or help with estimating the spatial and economic requirements for the implementation of the measures planned. The program can also be used by students of economic or technical fields who encounter the issue during their studies.

The „Measure selection" and „Enforcement tools" modules use the MCA method in their decision-making mechanisms [11, 12]. It allows comparison of evaluation criteria from different areas of interest (with different units, binary, etc.). In the case of the „Measures selection" module, criteria are chosen for selection that consider natural, technical, and legislative restrictions for construction, which result mainly from the requirements of the relevant technical standards [17, 18]. The functional type of the development area considers the appropriateness of the application of individual measures for different types of urban development [10]. It also includes criteria of social need (e.g. the need to deals with drought, floods) or criteria that resulted from communication with representatives of local governments (cost of implementation, need for maintenance). The MCA process can also work with the individual preferences of the evaluator. In the case of RWM, this means that the user can enter this process and modify the set values of the preference matrix. The default setting was made after extensive discussion by the research team of the SS03010080 project. The evaluation criteria in the „Enforcement tools" module were selected and evaluated mainly on the basis of a professional literature search (both Czech and foreign) and on the basis of experience from pilot sites and consultations with state administration representatives [19].

The hydrological characteristics produced by the „Measure dimensioning" module are calculated on the basis of the rational method, the modification of which for these purposes is specified in the ČSN 75 6101 standard. During the calculation, the RWM program considers constant-intensity rain with periodicity p = 0.2 and duration t = 15 min. The values for these rains are taken from the TNV 75 9010 standard. However, the question is whether the data on these rains are up-to-date. The list of stations, for example, also includes stations that no longer exist (e.g., Plzeň – Doudlevce). However, RWM offers the possibility to enter current, locally valid data.

The selection of hydrological characteristics considers general requirements for rainwater management. The value of maximum runoff is important for the user, especially in connection with drainage of water that has not been infiltrated or retained on the property. This runoff is drained in the direction of the hydraulic gradient into the recipient (rain sewer, watercourse). In their regulations, the recipient administrator can require compliance with the maximum value of the inflow into the recipient. The specific runoff follows the requirements of the TNV 75 9011 standard, which recommends that the rainwater runoff does not exceed the value of 3 l/s/ha of the specific runoff. The unprocessed volume of stormwater indicates the value of the precipitation volume that has not been processed (retained, infiltrated) and will flow from the area. If the user wants to retain all the stormwater, they will know how much water still needs to be retained or infiltrated.

RWM also works with the predicted influence of climate change on rainfall intensity values. In this regard, some studies focus on seasonal forecasts [4, 13] while others on specific rainfall duration [14]. Studies agree that there will be an increase in precipitation intensity. The question remains how big this increase will be. RWM uses a relative increase in precipitation intensity for these facts (and also due to their uncertainty). By default, the value is set to 15 %, while the allowed intensity increase range is 10–20 %.

The results also include the blue-green infrastructure coefficient (BGIC). This index evaluates RWM measures in terms of green ecosystem functions and natural water cycle functions. The index was introduced within the SS03010080 project. The reason for its introduction was the absence of a similar index in the Czech Republic. The most similar indices in this respect were the HGF (Helsinki Green Factor) [20] and BAF [21] indices. However, none of these factors is adapted to the Czech environment – it does not provide values for all intended RWM measures and categories of areas set for runoff coefficients, on the basis of which the calculation is carried out using the rational method. For this reason, the missing values were expertly estimated based on the analysis of foreign literature [20–23].

CONCLUSIONS

The aim of this paper is to present RainWaterManager (RWM) software, to describe its basic functions, and the possibilities of its use. RWM software is designed as a supporting element in deciding on the choice of a suitable measure for rainwater management (RWM). It helps users with the choice of a suitable RWM measure by determining its indicative scope, effectiveness, cost-effectiveness, and by finding mechanisms to enforce the implementation of these measures in practice. RWM also includes a catalogue of RWM measures. In the catalogue, individual measures are described in detail and examples of their application in practice are given. RWM is primarily intended for users from public administration and the general public. However, its results can be used by civil engineers, planners, and university students who encounter the planning of RWM measures or the evaluation of their socio-economic functions during their studies.

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References

[1] CzWA. *Studie hospodaření se srážkovými vodami v urbanizovaných územích*. Prague: Czech Water Association, MoE, 2019.

[2] MORISON, P. J., BROWN, R. R. Understanding the Nature of Publics and Local Policy Commitment to Water Sensitive Urban Design. *Landscape and Urban Planning*. 2011, 99, pp. 83–92.

[3] HLAVÍNEK, P., PRAX, P., KUBÍK, J. *Hospodaření s dešťovými vodami v urbanizovaném území*. Brno: ARDEC, 2007.

[4] RULFOVÁ, Z., BERANOVÁ, R., KYSELÝ, J. Climate Change Scenarios of Convective and Large-Scale Precipitation in the Czech Republic Based on EURO-CORDEX Data. *International Journal of Climatology*. 2017, 37(5), pp. 2 451–2 465.

[5] VÍTEK, J., STRÁNSKÝ, D., KABELKOVÁ, I. et al. *Hospodaření s dešťovou vodou v ČR*. Prague: ZO ČSOP Koniklec, 2015. 127 pp.

[6] AUBRECHTOVÁ, T., GELETIČ, J., HALÁSOVÁ, O. et al. Administrativní reakce českých měst na adaptační procesy související s klimatickými změnami. *Urbanismus a územní rozvoj*. 2019, 22(1), pp. 4–12.

[7] VÍTEK, J. et al. *Hospodaření se srážkovými vodami – cesta k modrozelené infrastruktuře. Olomoucké stavební standardy k integraci modrozelené infrastruktury*. Olomouc: JV PROJEKT VH, s r. o., 2018.

[8] STRÁNSKÝ, D., KABELKOVÁ, I. Systém dokumentů pro koncepční hospodaření se srážkovou vodou v obcích. *Urbanismus a územní rozvoj*. 2022, 25(5), pp. 40–44.

[9] MACHÁČ, J., HEKRLE, M. et al. *Modrozelená města: Příklady adaptačních opatření v ČR a jejich ekonomické hodnocení*. Ústí nad Labem: Institute for European Environmental Policy (IEEP), 2022. 86 pp. ISBN 978-80-7561-405-6.

[10] KOPP, J., HEJDUKOVÁ, P., JEŽEK, J. et al. *Katalog opatření efektivního hospodaření se srážkovou vodou na rozvojových plochách urbanizovaných území*. Pilsen: University of West Bohemia, 2022. 108 pp.

[11] FIALA, P., JABLONSKÝ, J., MANAS, M. *Vícekriteriální rozhodování*. Prague: University of Economics and Business, 1997.

[12] BROŽOVÁ, H., HOUŠKA, M., ŠUBRT, T. *Modely pro vícekriteriální rozhodování*. Prague: Czech University of Life Sciences, 2009.

[13] FISCHER, A. M. et al. Projected Changes in Precipitation Intensity and Frequency in Switzerland: A Multi-Model Perspective. *International Journal of Climatology*. 2015, 35(11), pp. 3 204–3 219.

[14] SVOBODA, V. et al. Projected Changes of Rainfall Event Characteristics for the Czech Republic. *Journal of Hydrology and Hydromechanics*. 2016, 64(4), p. 415.

[15] ČSN 75 6101. *Stokové sítě a kanalizační přípojky*. Prague: Czech Office for Standards, Metrology and Testing, 2012.

[16] KOPP, J., HEJDUKOVÁ, P., KUREKOVÁ, L. et al. Kategorizace nástrojů prosazování efektivního hospodaření se srážkovou vodou na rozvojových plochách. *Trendy v podnikání*. 2022, 12(1), pp. 14–23, ISSN 1805-0603.

[17] ČSN 75 9010. *Vsakovací zařízení srážkových vod*. Prague: Czech Office for Standards, Metrology and Testing, 2012.

[18] TNV 75 9011. *Hospodaření se srážkovou vodou*. Praha: Sweco Hydroprojekt a. s., 2013.

[19] KOPP, J. et al. Možnosti efektivního hospodaření se srážkovou vodou na rozvojových plochách urbanizovaných území. *Regionální rozvoj mezi teorií a praxí*. 2021, 4, pp. 1–15.

[20] JUHOLA, S. Planning for a Green City: The Green Factor Tool. *Urban Forestry & Urban Greening*. 2018, 34, pp. 254–258.

[21] BECKER, C. W. et al. *Der Biotopflächenfaktor als ökologischer Kennwert. Grundlagen zur Ermittlung und Zielgrößenbestimmung*. Berlin 1990.

[22] *Climate-Proof City – The Planner's Workbook*. Helsinki: City of Helsinki Environment Centre, 2014. Available at: https://ilmastotyokalut.fi/en/

[23] *Developing the City of Helsinki Green Factor Method. Report summary. iWater – Integrated Storm Water Management. Interreg Central Baltic*. Helsinki: City of Helsinki Environment Centre, 2016. Available at: https://www.integratedstormwater.eu

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Protected areas of natural water accumulation – their meaning in the current system of water environment protection

ZDENĚK SEDLÁČEK, JITKA NOVOTNÁ, MILENA FOREJTNÍKOVÁ

Keywords: protected area of natural water accumulation – protected landscape area – National Park – surface water and groundwater protection – farming on agricultural and forest land

ABSTRACT

This article discusses the development, management, and use of the landscape in the form of a declaration of a Protected Area of Natural Water Accumulation (CHOPAV). It examines the importance of this method of protection in the water protection system under the requirements of the Water Framework Directive and other European directives which have been incorporated into the legislation of the Czech Republic. It looks at the possibilities of using this tool in water management to deal with problems caused by climate change. Based on the research and analysis carried out, the article recommends modifications to the CHOPAV regime and area modifications, as well as expansion to other sites.

INTRODUCTION

In the former Czechoslovakia, water management was handled systematically; legislative instruments, a theoretical approach to water protection, and rational use and development of water resources were at a good standard. Application of the proclaimed principles in practice was less successful. After the Czech Republic joined the European Union, EU directives in the field of water management had to be adopted and reflected in our legislation. There was an effort to preserve all functional instruments and modify them in a form compatible with the requirements of these directives. The main document that was incorporated into the legislation of the Czech Republic was the Water Framework Directive; however, it focuses mainly on the watercourse itself, including its morphology, while paying little attention to the landscape in the basin. Legislative tools used for the comprehensive protection of basins, such as protected areas of natural water accumulation (chráněné oblasti přirozené akumulace vod; CHOPAV), have thus become a certain relict in the new water management system.

Current research as well as a number of projects focus on investigating the effects of climate change and the possibilities of mitigating its negative impact. In addition to the search for new procedures and the enforcement of new regulations and decrees, the possibilities of using existing tools are being explored; protection in the form of CHOPAV is one of them.

The knowledge gained during the implementation of the project *„ADAPTAN II – Integrated approaches to the adaptation of the landscape of the Moravian-Silesian Region to climate change"* led us to writing this article. We are trying to find an answer to the following questions: In the context of the current ongoing climate change, does the protection of in the form of CHOPAV make sense? And is large-scale nature conservation in the form of national parks (NP) and protected landscape areas (PLA) sufficient enough for surface water and groundwater protection?

METHODS

This issue falls within the responsibility of several ministries; apart from the Ministry for Regional Development (spatial planning), it is also the Ministry of the Environment (water protection) and, in particular, the Ministry of Agriculture. It is responsible for basin management, the provision of drinking water, and connecting municipalities to sewage systems; at the same time, the required measures and regulations affect agricultural management and forestry.

In searching for answers to the above questions, we chose the following procedures: different types of area protection were compared with the requirements imposed by law and government regulations for management and activities in CHOPAV. Subsequently, we analysed the overall relationships within area protection by various legislative tools. For the analysis, we used ESRI ArcGIS geo-information software designed to display and process geographic data using DIBAVOD and ZABAGED databases. Subsequently, we searched for cases where the affiliation of an area to the declared CHOPAV was used to assess the permissibility of carrying out certain activities in the area. One of the important steps was also a comparison of the approach to comprehensive landscape and water protection in the Czech Republic and in neighbouring countries.

Based on discussion of the obtained results, we made concrete proposals and recommendations for the further development and use of water protection through CHOPAV.

RESULTS

CHOPAV in past and current legislation

Searching and linking related legislation brought some fundamental insights.

The first mention of CHOPAV in the Czechoslovak legal environment is in the Water Act of 1973 (No. 138/1973 Coll., Part Three – Water Protection, Section 1 – Protection of Natural Accumulation of Water and Water Resources, Section 18).

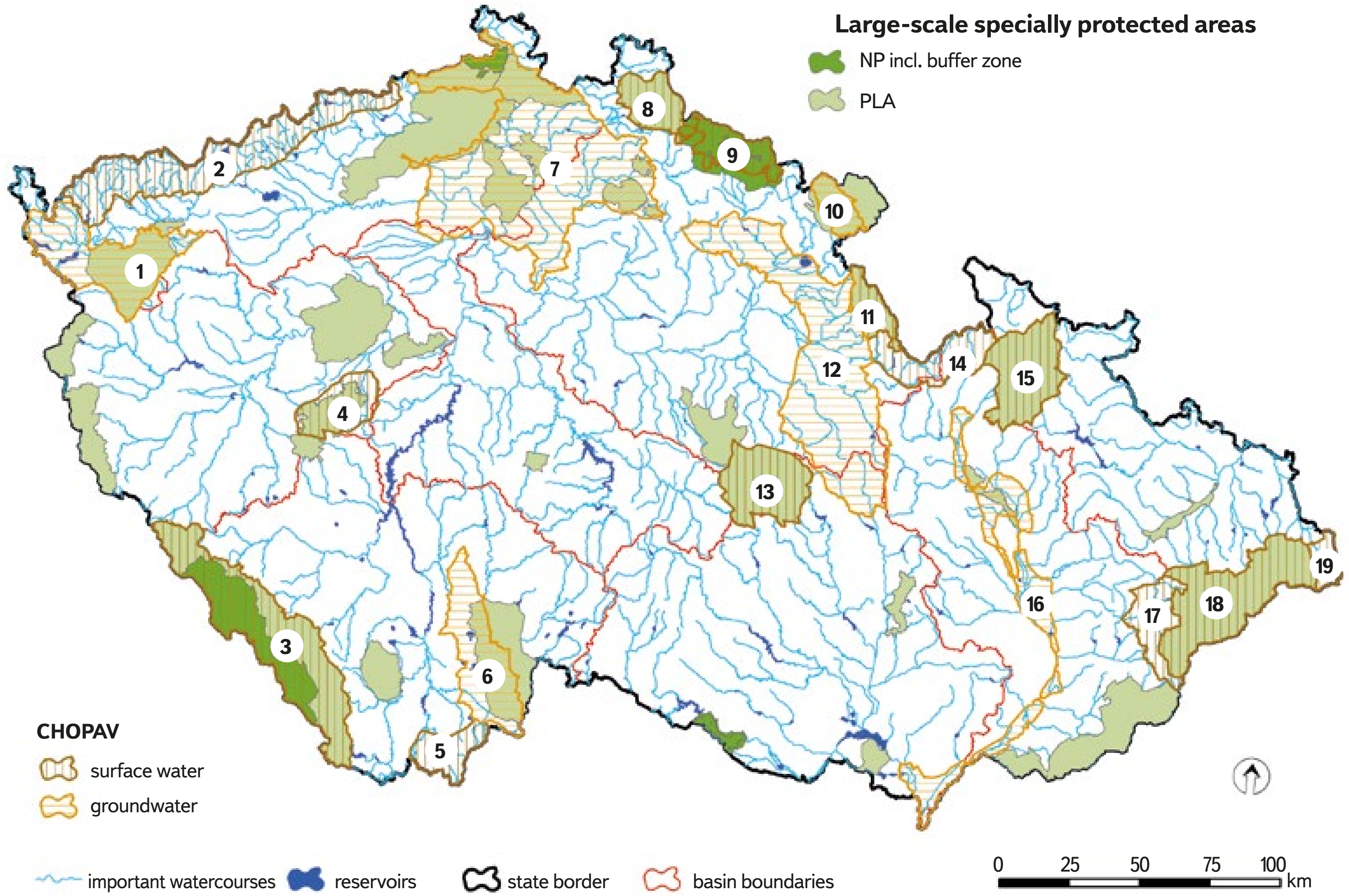

Fig. 1. CHOPAV areas compared with large-scale nature protection – numerical designation of CHOPAV areas (1 – Chebská pánev and Slavkovský les, 2 – Krušné hory, 3 – Šumava, 4 – Brdy, 5 – Novohradské hory, 6 – Třeboňská pánev, 7 – Severočeská křída, 8 – Jizerské hory, 9 – Krkonoše, 10 – Polická pánev, 11 – Orlické hory, 12 – Východočeská křída, 13 – Žďárské vrchy, 14 – Žamberk – Králíky, 15 – Jeseníky, 16 – Quaternary of the Morava river, 17 – Vsetínské vrchy, 18 – Beskydy, 19 – Jablunkovsko)

It mentions that the government can designate areas with natural conditions for significant natural water accumulation as protected water management areas and prohibit activities that threaten water management conditions in the area. During the period of validity of this law, four amendments were issued which, however, no longer applied to CHOPAV. The individual CHOPAVs were declared gradually with the entry of relevant government regulations into force [1].

In these legal regulations, the overall scope was determined and prohibited activities were defined by name and individually for each area.

In the current wording of the Water Act No. 254/2001 Coll. [2], CHOPAV is mentioned in several sections; the important thing is that this type of area protection is still valid, even after the admission of the Czech Republic to the EU.

According to Section 28 of this law, CHOPAV aims at the preventive protection of areas in which water naturally accumulates against activities that could endanger its quality or quantity. Protection is implemented through exhaustively listed bans (Section 28, paragraph 2), the scope of which is determined by government regulation. The law gives the government general authority to declare protected areas of natural water accumulation and the extent of restrictions or prohibitions of activities that can be implemented in them. Another important provision in Section 108 is that the competence of the central water authority in CHOPAV matters is exercised by the Ministry of the Environment.

The boundaries of the existing areas are defined in Government Regulations (GR) No. 40/1978 Coll., No. 10/1979 Coll., No. 85/1981 Coll., where all prohibitions are defined and later adopted into the currently valid Water Act. They are mainly prohibitions to:

- drain forest land,
- drain agricultural land,
- extract peat,
- perform surface extraction of minerals,
- carry out other work that would lead to the uncovering of a continuous groundwater level.

Currently, 19 protected areas of natural water accumulation are declared in the Czech Republic by these government regulations from 1978–1981 [1]. Of this number, 13 areas are focused on surface water protection and six areas on groundwater protection. A summary map of CHOPAV areas including their type is shown in *Fig. 1*.

These areas were declared in accordance with the legislation in force at the time; the question is currently arising about the appropriateness or even the necessity of revising the requirements of the then government regulations with regard to the requirements of the current legislation. We are also considering whether it would be appropriate to establish this type of protection for other areas. Although the conditions for both types of CHOPAV areas are similar, a distinction must be made between areas protected as surface water or groundwater. *Fig. 2* shows a comparison of the characteristic differences of the landscape in both types: in the case of groundwater, it is often the protection of the floodplain of the lower reaches of large rivers; in the case of surface water, it is mainly the protection of mountain areas.

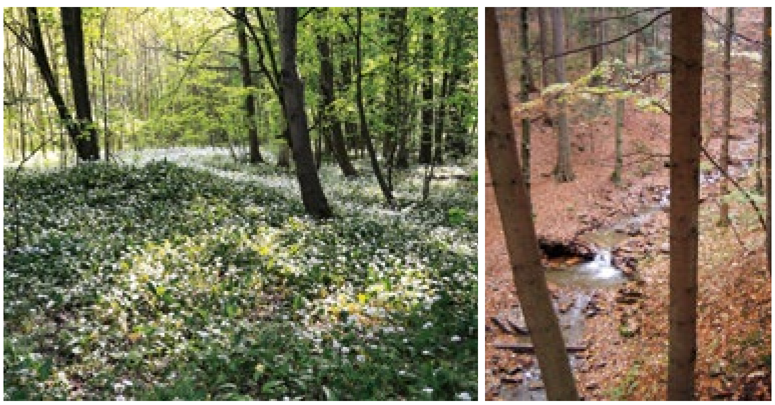

Fig. 2. Landscape in CHOPAV area of groundwater and surface water: Quaternary of the Morava river in Litovelské Pomoraví, Jablunkovsko – upstream of the Lomná river

Relationship between CHOPAV and other large-scale area protection

In the Czech Republic, wildlife and landscape have been protected by legislative tools of various nature since the second half of the 20th century (1955) to the present day (scope of the Act on the Protection of Nature and Landscape No. 114/1992 Coll.).

One of the most important tools for the protection of wildlife and the landscape is the protection of land, which is carried out through specially protected areas. The Nature and Landscape Protection Act [2] defines six categories of specially protected areas, of which national parks (NP) and protected landscape areas (PLA) significantly extend or exceed the area of a total of 13 CHOPAV areas. Other categories, such as national nature reserves (NNR), nature reserves (NR), national natural monuments (NNM), and natural monuments (NM), do not have a decisive influence on activities in CHOPAV, as well as areas included in the Natura 2000 system and geoparks.

Sites where CHOPAV areas were declared are sometimes completely, sometimes partially covered by a PLA or NP (*Fig. 1*). Their overlap was based on what was protected by the given current legislative tool and what was considered important at that time.

An overview of the scope of CHOPAV areas and their overlap with nature protection areas (PLAs, NPs) is shown in *Tab. 1*. Litovelské Pomoraví PLA extends only marginally into the CHOPAV area of Quaternary of the Morava river. Český ráj PLA was expanded in 2002, and Kokořínsko – Máchův kraj PLA was also expanded in 2014. In the case of Šumava, the PLA was declared in 1963 and the NP in 1991. Severočeská křída CHOPAV still extends marginally into the České středohoří, Labské pískovce, and Lužické hory PLAs, as well as into Bohemian Switzerland NP.

Tab. 1. Relation of areas that belong to water protection under CHOPAV, protected landscape area (PLA), and national park (NP)

CHOPAV	**Year of declaration**	**Other area protection**	**Year of declaration of other protection (PLA, NP)**
Jablunkovsko	1979	none	---
Krušné hory			
Novohradské hory			
Vsetínské vrchy			
Žamberk – Králíky			
Brdy	1978	Brdy PLA	2016
Beskydy		Beskydy PLA	1973
Jeseníky		Jeseníky PLA	1969
Jizerské hory		Jizerské hory PLA	1967
Orlické hory		Orlické hory PLA	1969
Krkonoše		KRNAP	1963
Šumava		PLA/NP	1963/1991
Žďárské vrchy		Žďárské vrchy PLA	1970
Chebská pánev and Slavkovský les	1981	Slavkovský les PLA	1974
Severočeská křída		Český ráj PLA/ Kokořínsko – Máchův kraj PLA	1955, 2002/1976, 2014
Polická pánev		Broumovsko PLA	1991
Třeboňská pánev		Třeboňsko PLA	1979
Kvartér řeky Moravy		Litovelské Pomoraví PLA – partly	1990
Východočeská křída		none	---

Relationship between CHOPAV and the LAPV basin

The area protected as a site for the accumulation of surface water (lokalita pro akumulaci povrchových vod, LAPV) is a designation for the area earmarked for the possible construction of a water reservoir. Activities are only permitted which do not make it impossible or significantly difficult for the future use of the site for surface water accumulation. For this purpose, the area must be morphologically, geologically, and hydrologically suitable. The area protected for the accumulation of surface water is a legislative term defined in the Water Act, which was added as a part of its amendment in 2008.

Individual areas are listed in the General of Areas Protected for Surface Water Accumulation (General LAPV) [3], which is prepared by the Ministry of Agriculture in agreement with the Ministry of the Environment. The purpose of their protection is that if necessary, these sites can be used in the long term as one of the adaptation measures against climate change. These sites are continuously and repeatedly checked using the latest knowledge about climate development (e.g. Vizina et al. [4]). Sites enter the spatial planning process as

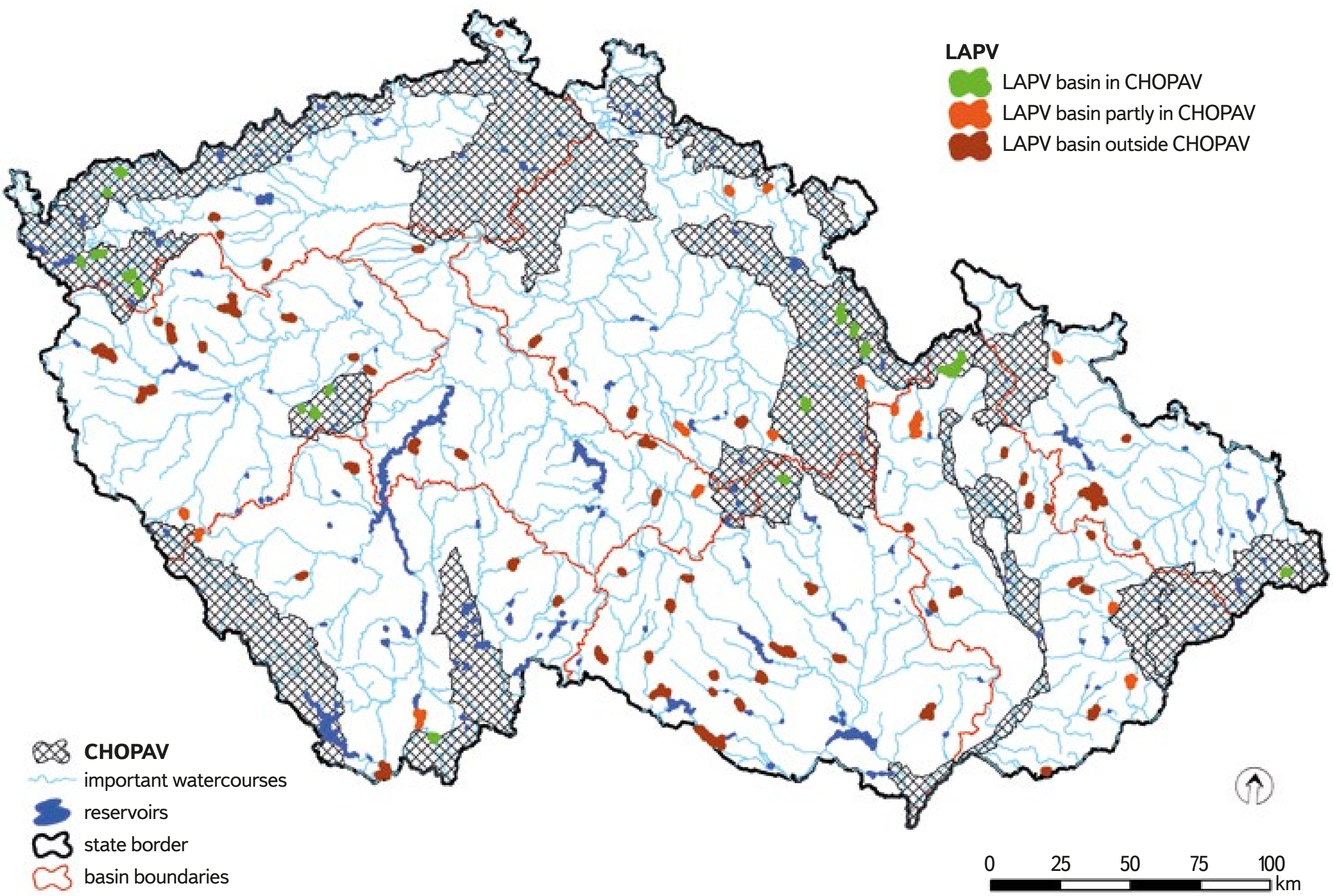

Fig. 3. CHOPAV areas in relation to basin sites for the accumulation of surface water

a „area reserve" at the level of the Principles of Regional Development. The second version of General LAPV, published in 2020, is the basis for the map in *Fig. 3*.

LAPV category A (whose importance for water management lies primarily in the ability to create or supplement sources for drinking water supply and possibly perform other functions, especially positive influence on the runoff conditions of large basins) as well as LAPV category B (which are suitable for flood protection, coverage of water abstraction requirements and improvement of discharge) are currently only protected to the extent of the future flooded area. The basins of these possible future reservoirs have no legislative protection resulting from the inclusion of the relevant LAPV in the General.

In the case of existing water reservoirs, the protection of their basins is ensured in the form of protection zones for vulnerable water resources. For the LAPV basins, there is currently no targeted protection. Therefore, CHOPAV could be a suitable tool for such protection. For this reason, we carried out a spatial analysis of the current condition, and in the map in *Fig. 3*, LAPVs are shown according to the protection of their basins due to the existence of CHOPAVs. We consider those whose entire basin falls within the CHOPAV to be the best protected, the second group are those where at least part of their basin in the spring area is protected. The third group consists of those that do not currently have any watershed protection. These sites, which are also found in larger groups, such as in Vysočina or in western Bohemia, give impetus to the expansion of an existing CHOPAV, or to the declaration of a new one.

Other legislative tools for comprehensive protection of the aquatic environment

There are other tools in the environmental protection system that can be used for general water protection. However, they are directed only to a specific activity. For example, the requirements of the Nitrate Directive [5] fall under agricultural management. It is an EU directive created to protect water from nitrate pollution from agriculture. According to its requirements, so-called vulnerable areas have been earmarked which already show an increased nitrate content in water and where stricter requirements for agricultural land management are applied. Compared to the long-declared and unchanged CHOPAV, these vulnerable areas are regularly updated according to monitoring results.

All surface waters in the Czech Republic were also defined as sensitive areas according to the Urban Waste Water Treatment Directive [6]. It aims to limit the entry of phosphorus into surface waters, which is especially important for existing and future water reservoirs.

Almost a third of the forests in the Czech Republic are forests of water management significance with specific water management functions. These are forests in protection zones for vulnerable water resources and forests in protected areas of natural water accumulation. Forests in mountain CHOPAV have a water protection, anti-erosion, infiltration, and drainage function with the same management as in protection zones for vulnerable water resources. However, if there is destruction of forest stands or salvage cutting, technical melioration – drainage – must be carried out on the resulting clearings in order to prepare favourable conditions for forest restoration. There is thus a conflict with the requirements of the Water Act, where for CHOPAV *"... it is flatly prohibited to drain forest land"* [7].

The position of CHOPAV in the spatial planning process

When proposing the use of land for certain functions and activities, it is necessary to deal with a number of prohibitions or restrictions resulting from various legal regulations. These prohibitions and restrictions enter the spatial planning activity as „Limits on land use." This means restrictions due to the protection of public interests, restrictions resulting from legal regulations, or from the characteristics of the area. Area limits are therefore not another legislative tool; on the contrary, in the form of area analytical documents [8], they summarize the legislative requirements for the given phenomenon in one document, and are thus an aid for those preparing spatial plans.

The Ministry for Regional Development issued Methodological Instructions [9], where it refers to „Limits of land use", specifically to Limit No. 4.1.114 – Land use in declared CHOPAVs.

Part of this Limit is presented in *Tab. 2*.

Tab. 2. Limits and other requirements for land use, as of 1st July 2023

L 4.1.103 Use of land in declared protected areas of natural water accumulation (CHOPAV)

Subject of limitation	Activities that may have an impact on natural conditions in protected areas of natural water accumulation (mining, forest management, agricultural activities, etc.).
Reasons for limitation	Protection of surface water and groundwater quality in areas of natural water accumulation.
Expression of limit	Protected areas of natural water accumulation (hereinafter CHOPAV) are a provision of § 28 of Act No. 254/2001 Coll. defined as areas which due to their natural conditions constitute a significant natural water accumulation. CHOPAV is declared by the government through its regulations. In CHOPAV, to the extent determined by government regulations, the following is prohibited: — reduce the extent of forest land — drain forest land — drain agricultural land — extract peat — surface extract minerals or carry out other work that would lead to the exposure of a continuous groundwater level — mine and process radioactive raw materials — store radioactive waste — store carbon dioxide in hydrogeological structures with usable or exploited groundwater reserve

CHOPAV issues focused on groundwater

Geological structure of the CHOPAV areas in the Czech Republic

The geological structure of the Czech Republic is very complex due to the existence of two completely different units with completely different geological development. A certain degree of generalization is necessary for its description and subsequent work. The Hydroecological Information System (HEIS) was used for a simplified description of the geology in the CHOPAV areas:

— *Carpathian flysch* – Beskydy, Jablunkovsko, Vsetínské vrchy,
— *Metamorphites and sediments of the culm* – Jeseníky,
— *Metamorphites* – Žamberk – Králíky, Orlické hory, Žďárské vrchy, Krkonoše, Krušné hory, Šumava,
— *Quaternary sands, gravels* – Quaternary of the Morava river,
— *Cretaceous sandstones, claystones* – Východočeská křída, Polická pánev, Severočeská křída,
— *Acidic igneous rocks and volcanics, tertiary sediments* – Jizerské hory, Chebská pánev and Slavkovský les,
— *Mafic igneous rocks and volcanics* – Brdy,
— *Tertiary sediments* – Třeboňská pánev.

According to lithology, the aquifer rock environment that forms the subsoil of the CHOPAV area is vulnerable to pollution wherever overlying hydrogeological insulators, which could prevent it, are not developed. Precipitation infiltration occurs on the surfaces of hydrogeological collectors, while hydrogeological insulators prevent pollution in areas of drainage and groundwater accumulation. Basin structures which are Cretaceous formations and Tertiary sediments are well protected in the water accumulation areas by overlying insulators. Crystalline rocks are more vulnerable from the point of view of groundwater formation which, like CHOPAV, are protected from the point of view of surface water and, at the same time, form a subsidy (infiltration) background for basin structures. Examples include the Jeseníky Mountains and Quaternary of the Morava river (two adjacent CHOPAVs) and Chebská pánev (one CHOPAV).

Groundwater zones

Groundwater zones were newly defined by Decree No. 5/2011 Coll., on the definition of groundwater zones and groundwater bodies, the method of assessing groundwater status and the requirements of programmes for the detection and assessment of groundwater status [10]. The groundwater zone is a basic balance unit and is *„defined on the basis of natural characteristics, especially according to hydrogeological conditions, type of irrigation, and groundwater circulation"*. If we compare the boundaries of CHOPAV (announced for groundwater in 1981) with the boundaries of groundwater zones, it is clear that they do not correspond in most cases (*Fig. 4*). *Tab. 3* shows all the groundwater zones that, with their projected area, extend into the CHOPAV area declared for groundwater. The situation at Severočeská křída CHOPAV is the most complex; it includes three layers of hydrogeological zones – basal collector zones, base layer zones, and upper layer zones.

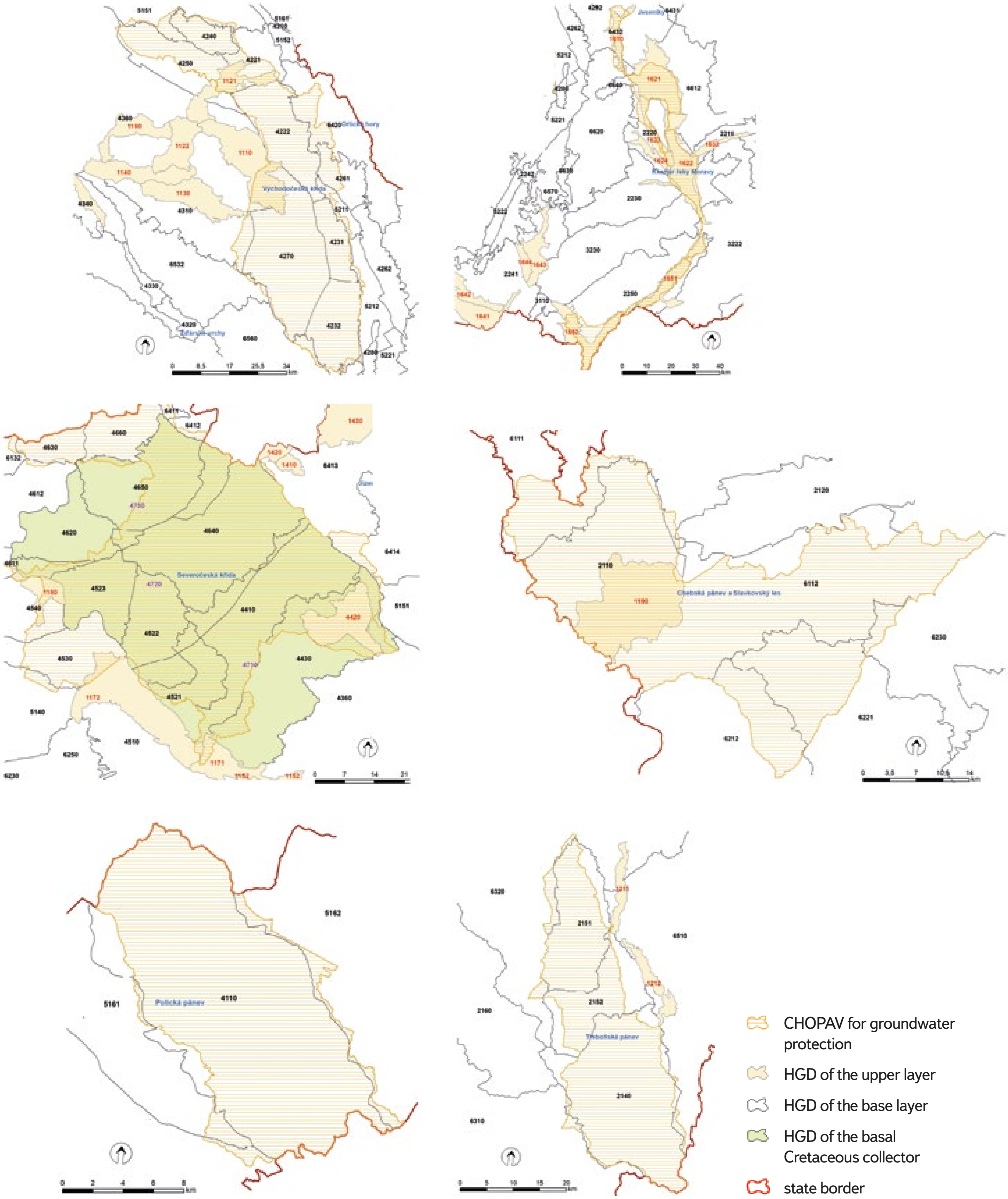

Fig. 4. CHOPAV areas in relation to groundwater zones

Tab. 3. Relationship between CHOPAV areas focused on groundwater and groundwater zones

CHOPAV	HGD of the basal Cretaceous collector	HGD of the base layer	HGD of the upper layer
Severočeská křída	4730, 4720, 4710	6132, 4630, 4660, 4611, 4612, 4620, 4650, 6411, 6412, 4640, 4410, 4430, 6414, 4521, 4522, 4523, 4530, 4540, 5140	1171, 1172, 1180, 4420
Chebská pánev and Slavkovský les	-	6111, 2110, 6112, 6221, 6230, 6212	1190
Polická pánev	-	5162, 4110, 4210, 5161	-
Třeboňská pánev	-	2140, 2152, 2151	-
Východočeská křída	-	4232, 4231, 4270, 5211, 4310, 4360, 4222, 4261, 6420, 4221, 4240, 4250	1121, 1110
Quaternary of the Morava river	-	2250, 2220	1651, 1652, 1622, 1610, 1621, 1623

The aim of CHOPAV is to limit activities that affect shallow groundwater circulation – reducing the infiltration capacity of precipitation (reducing the area of forest stands) or draining the landscape (land drainage); also, to eliminate interventions in aquifers that can lead to their damage – uncovering the groundwater level in the upper layer zones or mining of radioactive raw materials in basal collector zones.

Conflict of interests in practice – protection of groundwater versus gravel sand deposits

A significant conflict of interests is taking place in the Quaternary of the Morava river CHOPAV in the cadastre of Uherský Ostroh, on the border of the South Moravian and Zlín regions. The Moravský Písek – Uherský Ostroh gravel-sand deposit is demarcated on the Uherský Ostroh cadastre, the extraction of which would expose the free groundwater level. However, this should not happen within CHOPAV. At a distance of about 500 m from the boundary of the exclusive deposit, there is the boundary of the first stage protection zone of the Bzenec Water Resource – complex of receiving well III north. Simultaneously, the active zone of the floodplain runs through the exclusive deposit. Drinking water from the Bzenec Water Resource – complex supplies 140,000 inhabitants in south-eastern Moravia. If the water from a flood penetrated into the exposed groundwater level, it would create a major problem for drinking water supply. A significant risk factor is the fact that, after the possible extraction of the gravel-sand deposit, the mining pit will have a groundwater level exposed even after the deposit restoration [11].

Approach to comprehensive landscape and water protection in neighbouring countries

In Slovakia, due to the common government in the past, 10 CHOPAV areas (chránené oblasti prirodzenej akumulácie vôd in Slovak) or protected water management areas (chránené vodohospodárské oblasti, CHVO) were declared by government decree, just as in the Czech Republic, in 1978 and 1987.

In contrast to the Czech Republic, the issue of CHVO areas in Slovakia has been unified and updated into one comprehensive approach for groundwater and surface water protection, namely in Act No. 305/2018 Coll. [12]. The aforementioned law is intended exclusively to protect the 10 most valuable areas in which the largest groundwater reserves are located. CHVO occupy 6,942 km^2, which represents 14.16 % of the total area of Slovakia. The largest part of the CHVO area is occupied by forests, which make up 67 % of the area. As in the Czech Republic, large-scale water protection in Slovakia is separated from landscape protection in the form of a national park or protected landscape area; the difference lies only between the method of administration and management requirements in these areas.

Other neighbouring countries do not have large-scale water protection in the form of our CHOPAVs; water protection is managed in basins in accordance with the Water Framework Directive. It is also one of the components, not a priority, in landscape protection in national parks and other types of nature conservation.

In Poland, protected areas are defined by the Act of 16 April 2004 on nature conservation (Ustawą z dnia 16 kwietnia 2004 r. o ochronie przyrody). Protected areas are declared in ten categories, two of which are large-scale – national park (park narodowy – 23 in total) and protected landscape area (park krajobrazowy – 125 protected areas). On the border with the Czech Republic lies Karkonoski Park Narodowy (Karkonosze National Park) adjacent to the Czech Krkonoše National Park, Park Narodowy Gór Stołowych (Stołowe Mountains National Park), which is a continuation of the Czech Broumovsko Protected Landscape Area, and also Śnieżnicki Park Krajobrazowy (Śnieżnik Landscape Park) adjacent to the Czech Králický Sněžník mountain range.

There are a total of 16 national parks in Germany. Nationalpark Sächsische Schweiz (Saxon Switzerland National Park) is adjacent to the Czech border, adjoining Bohemian Switzerland National Park. Another border national park is Bayerischer Wald (Bavarian Forest), which together with Šumava National Park forms one of the largest bilateral national parks in Central Europe. According to data from the Federal Agency for Nature Conservation, at the end of 2008 there were 7,203 protected landscape areas in the Federal Republic of Germany, covering 9.9 million hectares. This corresponds to approximately 28 % of the area of Germany. In German Saxony and Bavaria, as federal states neighbouring the Czech side, the following can be named as protected areas: Zittau Mountains (Zittauer Gebirge), occupying the German part of the Lusatian Mountains; Saxon Switzerland (Sächsische Schweiz), followed by the Elbe Sandstone Protected Landscape Area; Bohemian Switzerland National Park; and Upper Bavarian Forest Nature Park (Naturpark Oberer Bayerischer Wald).

There are six national parks in Austria. The oldest park is Hohe Tauern National Park (Nationalpark Hohe Tauern), which was declared in 1981. Thayatal National Park is adjacent to Podyjí National Park on the Czech side. Other categories such as „protected landscape areas" or „nature parks" only exist in some federal states. In 2009, there were 247 areas with the status of a protected area in Austria with an area of 2,696 km^2 (about 15 % of the country).

DISCUSSION

From a general point of view, CHOPAV is a very important tool for protecting the quantity and quality of surface water and groundwater where significant accumulations of these waters are created, which are used for water supply or potentially usable for water supply. The biggest legislative problem lies in the fact that, even though CHOPAV is included as an instrument of the Water Act (No. 254/2001 Coll., as amended), the individual areas were declared by Government Regulations No. 40/1978 Coll., No. 10/ 1979 Coll., No. 85/1981 Coll., within the previous Water Act No. 138/1973 Coll. This creates practical problems when requiring compliance with restrictive measures, including dealing with loss to landowners, etc.

There is an opinion (including the Ministry of the Environment) that where the area is protected, for example, in the form of a PLA, further protection is unnecessary. In practice, however, it appears that PLA administrations do not have the obligation and often do not even have the necessary expertise to comment on specific problems of protection, creation, and maintenance of conditions for natural water accumulation.

In this sense, CHOPAV appears to be a relatively weak legislative tool compared to the promotion of other interests, also due to the absence of an administrator of these areas. An example can be an important source of groundwater for supplying the population with drinking water – Březová nad Svitavou catchment area. The water source itself, including the protection zones, is located within Východočeská křída CHOPAV and should be uniformly managed in this area. In the case of conflict of interests in this area, it will be dealt with by the owner or operator of the water resource, a municipal authority, a municipality with extended powers, a regional authority with the water rights agenda, or the Ministry of the Environment as the last resort, who is, by law, the central authority; otherwise, there is virtually no one to contact within the entire CHOPAV.

CHOPAVs were announced with the aim of protecting areas that are important for the creation of surface water and groundwater sources. Since their announcement, there has been a significant legislative change in the area division of groundwater in the Czech Republic – the definition of groundwater zones. These are the basic area unit from the point of view of assessing the condition of groundwater and providing the basis for the performance of public administration and spatial planning. In the case of CHOPAVs, it would be advisable to revise their boundaries and bring them into line with the boundaries of the groundwater zones, or to make the boundaries of CHOPAV superior to groups of groundwater zones, if CHOPAV also includes the subsidy background of the upper layer zone.

One could also argue that protection in the form of CHOPAV is unnecessary as it is not applied in the majority of neighbouring countries. The opposite can be presented, for example, in the area of the Ore Mountains. On the German or Czech side, no comprehensive method of nature conservation is applied; it is always only a matter of small areas protecting only a specific natural feature, etc. The Ore Mountains CHOPAV is thus the only comprehensive protection of this area valuable for water management and nature.

Proposals for changes and new approaches to CHOPAV

From the water protection point of view, CHOPAV is still of irreplaceable importance. However, updating is necessary, similar to the one in Slovakia in 2019. Each existing area should be re-evaluated with regard to the overall scope, and also the modification of the given prohibited activities in relation to today's use of the area, nature conservation, and natural conditions.

Within the CHOPAV framework, it is forbidden to drain land. Due to the periods of drought, it would be advisable to eliminate the drainage on CHOPAV areas that occurred before they were announced, which would reduce water runoff from the landscape. For example, in Šumava PLA, which is also CHOPAV, these measures are already being implemented on peatland areas.

It would be appropriate to increase the legislative status of CHOPAV in relation to extraction of raw materials, which increases the risk of contamination of drinking water resources in the case of gravel sand extraction from groundwater.

The risk of connecting aquifers as a result of the implementation of boreholes for heat pumps, especially in chalk CHOPAVs, has appeared as a new problem. Boreholes for heat pumps that connect aquifers also represent a qualitative and quantitative risk for groundwater.

It is necessary to consider declaring some new areas with CHOPAV type protection. The first could be the floodplain and the spring area of the Odra river. Although part of the intended area is protected at least as Poodří PLA, it is not primarily focused on water protection. The forested water source area for the proposed Spálov water reservoir, which could be an important source of drinking water due to its volume, is not yet protected.

There are also spring areas in the Bohemian-Moravian Highlands that supply water to streams with probable future reservoirs. The protection of the relevant area could be a form of significant expansion of CHOPAV Žďárské vrchy or the creation of a completely new area with this type of protection.

CONCLUSION

The analyses carried out show that protection of the area through CHOPAV is justified even at the present time. In some respects, such as the protection of the LAPV watershed or the protection of groundwater from insensitive gravel sand extraction, it plays an irreplaceable role. However, there would be a need to update and modernize the relevant government regulations with regard to new protection requirements resulting, among other things, from adapting to climate change. It is also necessary to consider the expansion of existing areas or even the declaration of new areas with this type of protection.

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References

[1] *Nařízení vlády č. 40/1978 Sb., České socialistické republiky o chráněných oblastech přirozené akumulace vod Beskydy, Jeseníky, Jizerské hory, Krkonoše, Orlické hory, Šumava a Žďárské vrchy.*

Nařízení vlády č. 10/1979 Sb., České socialistické republiky o chráněných oblastech přirozené akumulace vod Brdy, Jablunkovsko, Krušné hory, Novohradské hory, Vsetínské vrchy a Žamberk – Králíky.

Nařízení vlády č. 85/1981 Sb., České socialistické republiky o chráněných oblastech přirozené akumulace vod Chebská pánev a Slavkovský les, Severočeská křída, Východočeská křída, Polická pánev, Třeboňská pánev a Kvartér řeky Moravy.

[2] *Zákon č. 254/2001 Sb., o vodách a o změně některých zákonů (vodní zákon).*

[3] *Generel území chráněných pro akumulaci povrchových vod a základní zásady využití těchto území.* Prague: Ministry of Agriculture, Ministry of the Environment, 2020.

[4] VIZINA, A., VYSKOČ, P., KOŽÍN, R., NOVÁKOVÁ, H. Potenciál chráněných území pro akumulaci povrchových vod pro zmírnění dopadů klimatické změny na zásobování pitnou vodou. *Vodohospodářské technicko-ekonomické informace.* 2023, 65(1), pp. 32–41. ISSN 0322-8916.

[5] *Směrnice Rady 91/676/EHS o ochraně vod před znečištěním způsobeném dusičnany ze zemědělských zdrojů.*

[6] *Směrnice Rady 91/271/EHS ze dne 21. května 1991 o čištění městských odpadních vod.*

[7] ČERNOHOUS, V., KANTOR, P., ŠACH, F. *Metodické postupy obhospodařování lesů s vodohospodářskými funkcemi.* Opočno: Výzkumný ústav lesního hospodářství a myslivosti, v. v. i., Výzkumná stanice Opočno, 2007.

[8] *Vyhláška č. 500/2006 Sb., Ministerstva pro místní rozvoj o územně analytických podkladech, územně plánovací dokumentaci a o způsobu evidence územně plánovací činnosti.*

[9] *Metodický návod k příloze č. 1 vyhlášky č. 500/2006 Sb., o územně analytických podkladech, územně plánovací dokumentaci a způsobu evidence územně plánovací činnosti.* Prague: Ministry of Regional Development, 2019. ISBN 978-80-7538-243-6 (PDF).

[10] *Vyhláška č. 5/2011 Sb., o vymezení hydrogeologických rajonů a útvarů podzemních vod, způsobu hodnocení stavu podzemních vod a náležitostech programů zjišťování a hodnocení stavu podzemních vod.*

[11] BURDA, P., NOVOTNÁ, J. *Uherský Ostroh 2 – těžba a úprava štěrkopísku a ovlivnění jímacích území Bzenec. Znalecký posudek.* GEOtest, a. pp., 2016.

[12] *Zákon č. 305/2018 Z. z. Národnej rady Slovenskej republiky o chránených oblastiach prirodzenej akumulácie vôd a o zmene a doplnení niektorých zákonov.*

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Emerging contaminants in wastewater – results of Joint Danube Survey 4 evaluated via the grey water footprint

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Keywords: grey water footprint – Joint Danube Survey – JDS4 – emerging contaminants – no-effect concentration – predicted no-effect concentration – PNEC – emerging contaminants – CEC – Contaminants of Emerging Concern

ABSTRACT

The Joint Danube Survey (JDS4), organized in 2019, provided a unique dataset on the occurrence of several hundred newly identified contaminants of emerging concern (CEC) in waters of the Danube river basin, including wastewater from selected wastewater treatment plants. In this study, published JDS4 data were used to assess the significance of individual substances identified in wastewater using the grey water footprint approach. Determining all newly identified contaminants is time-consuming and expensive, so it is reasonable to focus on the „most problematic" substances. The advantage of the grey water footprint assessment is conversion of the amount of discharged pollutants into the volume of water needed for dilution to an environmentally 'safe level', allowing comparison of different substances. Based on JDS4 data, out of several hundreds of substances detected, 33 were identified as potentially risky, according to set criteria. However, this list cannot be taken as definitive, as the level of knowledge about the harmfulness of individual substances quickly develops with regard to the risk currently attributed to them. Similarly, the JDS4 dataset reflects a specific data collection methodology, which may not capture all connections related to the impact of the occurrence of new substances on the environment.

INTRODUCTION

New or „emerging" contaminants are substances of anthropogenic origin that have been monitored in the environment for a relatively short time. Therefore their occurrence is not entirely mapped, and their effects on organisms, including humans, are not yet fully known. These mainly include chemical substances used and released into the environment through various pathways. In particular, it concerns residues from pharmaceuticals and personal care products (PPCP), pesticides and plant protection products (PPP), and industrial chemicals. They are generally referred to as Contaminants of Emerging Concern (CEC). These substances are not only detected in wastewater but also in surface, groundwater, and even drinking water. One of the main sources of CECs in the environment is wastewater treatment plants, which are not equipped to remove the full range of them [1].

The mapping of CECs in waters was a part of the 4th Joint Danube Survey (JDS4), carried out in 2019, in 13 countries belonging to the Danube river basin, including the Czech Republic. The main purpose of the Joint Danube Surveys is to ensure (in a short period) reliable and mutually comparable information on selected water quality indicators and the state of Danube ecosystems, and its main tributaries [2]. In water samples collected within JDS4, a broad-spectrum targeted screening of 2,362 chemical substances and their transformation products was performed, identifying 586 CECs [3]. One of the matrices analyzed within JDS4 was wastewater from 11 wastewater treatment plants (WWTPs), at their inflows and outflows. *Tab. 1* lists the monitored WWTPs.

Tab. 1. List of monitored WWTPs within JDS4

Site code	WWTP in	Country
JDS4-WW1	Donauwörth	Germany
JDS4-WW2	Linz-Asten	Austria
JDS4-WW3	Hodonín	Czech Republic
JDS4-WW4	Vrakuňa (Bratislava)	Slovakia
JDS4-WW5	Győr	Hungary
JDS4-WW6	Novo mesto (Ločna)	Slovenia
JDS4-WW7	Županja	Croatia
JDS4-WW8	Šabac	Serbia
JDS4-WW9	Giurgiu	Romania
JDS4-WW10	Vratsa	Bulgaria
JDS4-WW11	Uzhgorod	Ukraine

The grey water footprint is part of water footprint methodology, focusing on quantifying water consumption throughout the life cycle of a product, process, service, or within an organization. The grey water footprint is defined as a volume of water required to dilute discharged pollution to environmentally safe concentrations according to set environmental limits [4]. It is an environmental indicator that allows comparison of different pollutants by converting them into water volumes needed. The water footprint concept was introduced in 2002 [5], initially containing only quantitative assessments using blue and green water footprints. The expansion of the concept to also include qualitative assessment (grey water footprint) took place between 2005 and 2008 [6]. One of the first studies addressing the grey water footprint of wastewater treatment plants is a Romanian study from 2011 [7]. Since then, several studies have been published on the grey water footprint of WWTPs, addressing topics such as the impact of WWTPs on reducing the grey water footprint [8–11]; quantifying water and carbon footprints of WWTPs [9, 12]; and quantifying the grey water footprint of industrial wastewater [13–16]. Several studies also focused on pharmaceuticals, which form one part of CECs, and their grey water footprint [17–19].

All three mentioned works dealing with the grey water footprint of pharmaceuticals were limited in the scope of monitored substances. The aim of this study is to use the grey water footprint to assess the significance of individual CECs detected in wastewater during JDS4. Determining all CECs in wastewater is a time-consuming and cost-demanding task. Therefore, for routine monitoring, it is reasonable to select substances with the highest grey water footprint.

DATA AND METHODS

The concentrations of the detected CECs in the form of minimum and maximum values measured in individual matrices were published as supplementary material to an article by Nq et al. [3], together with Predicted No Effect Concentration (PNEC) values. PNEC is the concentration of a chemical substance that indicates the threshold at which adverse effects of exposure in the ecosystem have not (yet) been observed. These values are not intended to predict the upper limit of the concentration of a chemical substance that has a toxic effect [20]. In ecotoxicology, PNEC values are often used as a tool for assessing environmental risks [21], for example by the European Chemicals Agency (*REACH Regulation (EC) on Registration, Evaluation, Authorisation and Restriction of Chemicals*) and other toxicological agencies for assessing environmental risks [20]. PNEC value can be used in connection with Predicted Environmental Concentration (PEC) to calculate the Risk Characterization Ratio (RCR), also known as the Risk Quotient (RQ) or Hazard Quotient (HQ) [22]. The RCR equals the ratio of PEC/PNEC for a specific chemical substance and is a deterministic approach for estimating environmental risk at the local or regional scale. If PNEC exceeds PEC, it is concluded that the chemical substance poses no risk to the environment.

PNEC can be calculated from data on acute toxicity or chronic toxicity for one species, from data on Species Sensitivity Distribution (SSD), or from data obtained from field studies or ecosystem modelling tests [20, 23, 24]. Depending on the type of data used, an assessment factor is applied, that takes into account the reliability of the ecotoxicological data used when extrapolating it to the entire ecosystem. The value of the assessment factor depends on the uncertainty of the available data and ranges from 1 to 1,000 [20].

When data from acute toxicity tests are used to calculate PNEC values, the quality and relevance of these data must be verified. Ideally, this data should relate to species from multiple trophic levels and/or taxonomic groups [20]. The lowest determined concentration causing a 50% effect (L – lethal, E – effective, I – inhibitory) – LC50, EC50, IC50 – is then divided by the assessment factor for calculating PNEC, which is usually 1,000 [20].

When using chronic toxicity data to calculate PNEC, the No Observed Effect Concentration (NOEC) values are used. NOEC is the highest tested concentration at which no statistically significant ($p < 0.05$) difference in effect was observed in chronic toxicity tests compared to the control group. The lowest NOEC in the set of test data is divided by an assessment factor of 10 to 100, depending on the diversity of test organisms and the volume of available data. The more species or data there are, the lower the assessment factor is [20].

The Hazardous Concentration for 5 % of species (HC5) can also be used to derive PNEC. HC5 is the concentration at which 5 % of species in the SSD show an effect [10]. A statistical estimate of the SSD value of HC5 can be made from the results of a large number of ecotoxicological tests performed with a single substance using multiple trophic levels of test organisms (fish – invertebrates – algae). To determine PNEC, the HC5 value is then divided by an assessment factor of 1 to 5 [20]. However, in many cases, there may not be sufficiently large datasets available for determining the HC5 value using the SSD statistical procedure. In these cases, the NOEC value is used for PNEC derivation [20].

When using data on the effect of a substance from field studies or model tests, the value of the assessment factor is specific to the particular study or experiment [20].

Since most emerging contaminants do not have a set maximum permitted concentration in the aquatic environment (environmental standard), the PNEC value is used in calculating the grey water footprint according to the Equation 1:

$$GWF_i = \frac{L_i}{C_{max,}i - C_{nat,}i} = \frac{C_i \times Q}{PNEC_i - 0} = \frac{C_i}{PNEC_i} \qquad (1)$$

where: GWF_i is grey water footprint of substance *i*
L_i amount of discharged substance *i*
$C_{max,}i$ maximum permitted concentration of substance i in the aquatic environment (environmental standard)
$C_{nat,}i$ natural concentration of substance *i* in the aquatic environment; for anthropogenic substances = 0
C_i concentration of substance i in wastewater
Q flow rate of discharged wastewater; considering the study's objective, $Q = 1$ was assumed
$PNEC_i$ concentration of substance *i,* below which no adverse effect of exposure in the ecosystem is measured

A total of 419 CECs found in wastewater during JDS4 were included in the analysis. Of these, 311 CECs were detected in treated wastewater discharged from WWTPs, and 306 CECs were detected in wastewater entering WWTPs. Only 198 substances were found both in the influents and effluents to/from WWTPs. The largest proportion of detected CECs were pharmaceuticals. With a total of 165 substances, they represent 39.4 % of all detected CECs in wastewater (*Fig. 1*).

In the next step, values of the grey water footprint (GWF) of a unit volume were determined according to Equation 1, for the minimum and maximum

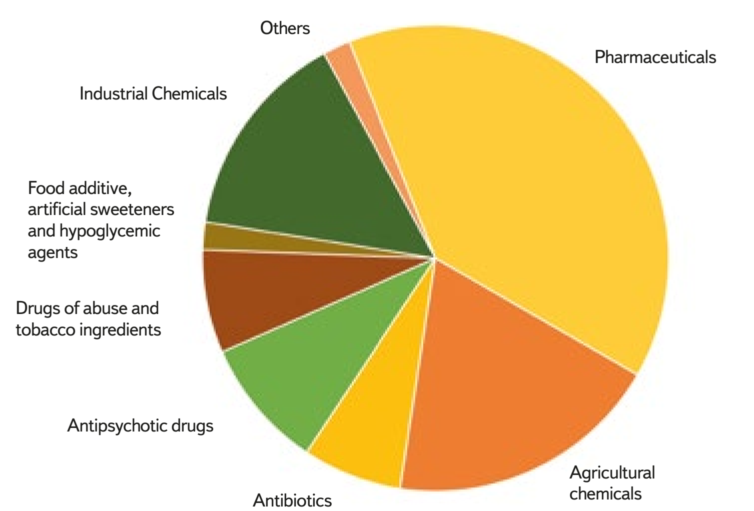

Fig. 1. Groups of emerging contaminants detected in wastewater within JDS4

Tab. 2. Risk CECs detected in wastewater during JDS4

Name	Cathegory	Concentration in effluent [ng/L]		Concentration in influent [ng/L]		Important in		PNEC [ng/L]	GWF in effluent [L/L]		GWF in influent [L/L]	
		min	max	min	max	effluent	influent		min	max	min	max
17beta-Estradiol	Pharmaceuticals	2.02	4.04	0.00	0.00	Yes		4.00E-04	5.04	10.09	N/A	N/A
4-tert-Octylphenol (4-t-OP)	Industrial chemicals	41.00	236.00	74.00	284.00	Yes		1.00E-01	0.41	2.36	0.74	2.84
Amoxicillin	Antibiotics	89.93	272.97	22.00	163.00	Yes		7.80E-02	1.15	3.50	0.28	2.09
Azithromycin	Antibiotics	4.85	202.33	1.10	24.00	Yes		1.90E-02	0.26	10.65	0.06	1.26
Candesartan	Pharmaceuticals	7.40	44.00	15.00	24.00	Yes	Yes	3.10E-03	2.39	14.19	4.84	7.74
Carbamazepine	Pharmaceuticals	28.00	343.00	21.00	181.00	Yes		5.00E-02	0.56	6.86	0.42	3.62
Carbamazepine-10,11-dihydro-10,11 dihyd-roxy	Pharmaceuticals	1,041.96	5,726.77	270.00	4,950.00	Yes		3.65E+00	0.29	1.57	0.07	1.36
Celecoxib	Pharmaceuticals	188.00	188.00	19.00	19.00	Yes		9.00E-02	2.09	2.09	0.21	0.21
Ciprofloxacin	Antibiotics	28.96	617.27	0.00	0.00	Yes		8.90E-02	0.33	6.94	N/A	N/A
Cloxacillin	Antibiotics	16.00	154.00	91.00	2,025.00	Yes	Yes	4.50E-02	0.36	3.42	2.02	45.00
Diazinon	Agricultural chemicals	1.69	304.86	4.54	4.54	Yes		1.00E-02	0.17	30.49	0.45	0.45
Diclofenac	Pharmaceuticals	280.00	1,312.00	330.00	1,320.00	Yes	Yes	5.00E-02	5.60	26.24	6.60	26.40
Dicloxacillin	Antibiotics	5.30	12.00	3.80	12.00	Yes		5.10E-03	1.04	2.35	0.75	2.35
Dodecyl-benzenesulfonate	Industrial chemicals	5.67	110.44	90.80	1,325.27		Yes	1.20E-01	0.05	0.92	0.76	11.04
Fendiline	Pharmaceuticals	171.00	171.00	0.00	0.00	Yes		2.40E-02	7.13	7.13	N/A	N/A
Fipronil	Agricultural chemicals	1.62	59.70	7.70	30.00	Yes	Yes	7.70E-04	2.10	77.53	10.00	38.96
Fipronil-sulfide	Agricultural chemicals	90.60	90.60	58.00	58.00	Yes	Yes	1.20E-02	7.55	7.55	4.83	4.83
Galaxolidone	Pharmaceuticals	859.00	9,884.00	20.00	2,947.00	Yes	Yes	1.00E-01	8.59	98.84	0.20	29.47
Imidacloprid	Agricultural chemicals	21.65	327.67	15.00	34.00	Yes	Yes	8.30E-03	2.61	39.48	1.81	4.10
Lorazepam	Antipsychotic drugs	209.00	209.00	236.00	236.00	Yes		9.60E-02	2.18	2.18	2.46	2.46
Metazachlor	Agricultural chemicals	13.57	962.50	0.00	0.00	Yes		2.00E-02	0.68	48.13	N/A	N/A
Methoprene	Agricultural chemicals	1.00	5.50	0.00	0.00	Yes		1.40E-03	0.71	3.93	N/A	N/A
N-Methyldodecylamine	Industrial chemicals	0.00	0.00	40.00	763.00		Yes	1.04E-01	N/A	N/A	0.38	7.34
Orlistat (Na)	Pharmaceuticals	0.00	0.00	16.00	35.00		Yes	8.00E-03	N/A	N/A	2.00	4.38

Name	Cathegory	Concentration in effluent [ng/L]		Concentration in influent [ng/L]		Important in		PNEC [ng/L]	GWF in effluent [L/L]		GWF in influent [L/L]	
		min	max	min	max	effluent	influent		min	max	min	max
PFOS	Industrial chemicals	3.50	27.00	27.00	27.00	Yes	Yes	6.50E-04	5.38	41.54	41.54	41.54
Phosphate-2-Ethylhexyl diphenyl (EHDP)	Industrial chemicals	9.50	129.59	0.00	0.00	Yes		1.80E-02	0.53	7.20	N/A	N/A
Phosphate-Tris(2-ethylhexyl) (TEHP)	Industrial chemicals	1.57	142.72	0.00	0.00	Yes		3.90E-02	0.04	3.66	N/A	N/A
pp-DDD	Agricultural chemicals	0.29	0.97	0.00	0.00	Yes		5.00E-04	0.58	1.95	N/A	N/A
pp-DDE	Agricultural chemicals	0.26	1.26	0.00	0.00	Yes		4.00E-04	0.65	3.16	N/A	N/A
Rifaximin	Antibiotics	0.00	0.00	25.00	95.00		Yes	2.50E-03	N/A	N/A	10.00	38.00
Telmisartan	Pharmaceuticals	11.00	844.00	7.10	2,021.00	Yes	Yes	5.50E-04	20.00	1,534.55	12.91	3,674.55
Terbutryn	Agricultural chemicals	1.36	103.52	0.41	2.70	Yes		6.50E-02	0.02	1.59	0.01	0.04
Trenbolone	Pharmaceuticals	3.10	5.70	0.00	0.00	Yes		1.30E-03	2.38	4.38	N/A	N/A

In the columns of maximum concentrations and PNEC, the three highest values are marked in red.

measured concentrations of each CEC at the inflow and outflow to/from WWTPs. Substances were designated as risky if their maximum GWF value was higher than 0.1 % of the maximum GWF value of the substance with the highest value (at WWTP inflow or outflow). The value of 0.1 % was chosen with regard to very high GWF values of the substance with the highest value at the inflow or outflow to/from WWTP (see Results) – which statistically represent an outlier value. Another reason that led to the choice of such a wide range is uncertainties associated with PNEC determination (see Discussion) when the assessment factor for different CECs ranges from 1 to 1,000.

RESULTS

Based on the procedure described in the Data and Methods section, 33 CECs were selected (*Tab. 2*). In total: 6 substances from the Antibiotics group; 1 substance from the Antipsychotics group; 11 substances from the Other Pharmaceuticals group; 9 substances from the Agricultural chemicals group; and 6 substances from the Industrial chemicals group.

Out of the 33 detected CECs, three substances (Rifaximin, N-Methyldodecylamine, and Orlistat (Na)) were not detected in the WWTPs effluents. And conversely, ten substances (17beta-Estradiol, Ciprofloxacin, Fendiline, Metazachlor, Methoprene, Phosphate-2-Ethylhexyl diphenyl (EHDP), Phosphate-Tris(2-ethylhexyl) (TEHP), pp-DDD, pp-DDE, Trenbolone) were not detected in the WWTPs influents. The criterion of the maximum GWF of a substance being higher than 0.1 % of the maximum GWF of the substance with the highest GWF value is met by 13 substances in WWTPs influents (*Fig. 2*) and by 29 substances in WWTPs effluents (*Fig. 3*).

The highest GWF, in both influent and effluent to/from WWTPs, was for Telmisartan (used for treating high blood pressure). The GWF of Telmisartan in the influent of WWTPs is more than 80 times higher than the second-highest GWF caused by the antibiotic Cloxacillin. In the case of WWTP effluents, the GWF of Telmisartan is more than 15 times higher than the second-highest GWF caused by Galaxolidone (a metabolite of the synthetic musk Galaxolide), whose maximum measured concentration in discharged wastewater was the highest among all monitored substances, almost 12 times higher than of Telmisartan. Within the JDS4, Galaxolidone was detected in all studied environmental matrices (WWTP influents and effluents, river water, groundwater, and biota) which confirms its high mobility and potentially high ecological risk.

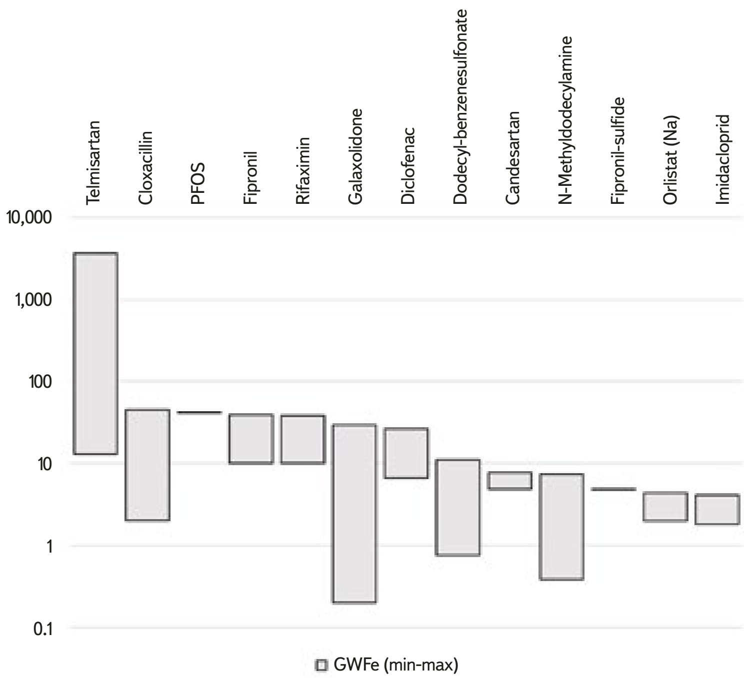

Fig. 2. Maximum and minimum GWF of risk substances at the WWTP inflows

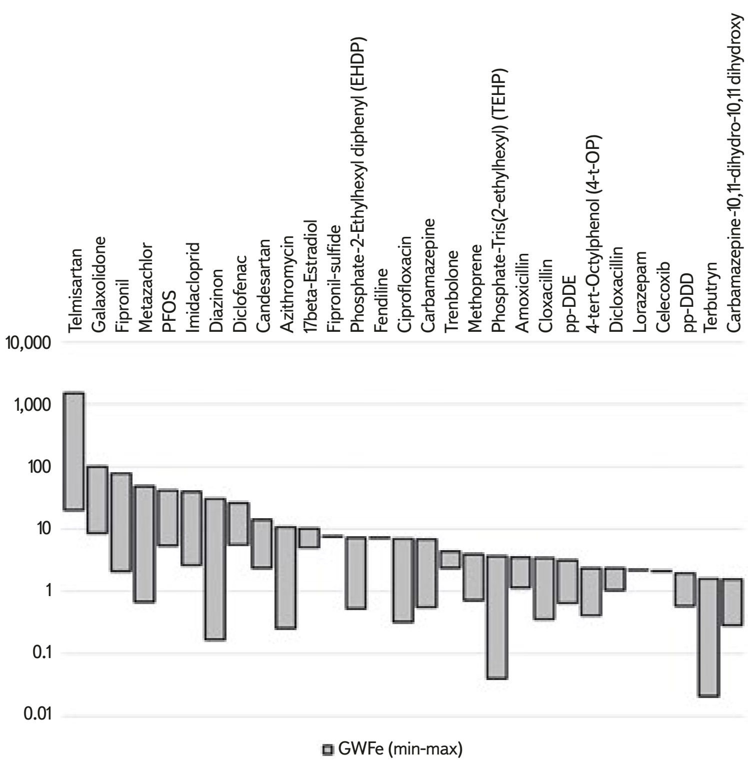

Fig. 3. Maximum and minimum GWF of risk substances at the WWTP outflows

DISCUSSION

Uncertainties associated with the use of PNEC

The use of PNEC values instead of maximum permitted concentrations (C_{max}) in Equation 1 leads to some uncertainties in the results obtained. The first uncertainty lies in the representativeness of the determination of PNEC values for individual substances. PNECs are based on toxicity and ecotoxicology tests that are performed on specific organism species and under certain conditions. Ecotoxicological data used to determine PNEC can be acquired from various studies that differ in the methods and conditions used. These differences can lead to different PNEC values for the same substance. For example, in this study, the contaminant of most concern is Telmisartan. This is due to a combination of high concentrations of this substance in wastewater and concurrently very low PNEC values (55 ng/L), which were adopted from the source study [3]. However, in other studies, even lower PNEC values for Telmisartan can be found, e.g. 37 ng/L [25] or 26 ng/L [26]. In contrast, the continuously updated ecotoxicological database NORMAN [27] reports the last valid value of 49 µg/L (November 27, 2022), i.e. three orders of magnitude higher.

When determining PNEC, various factors must be taken into account, such as the concentration and exposure of the substance in the environment. These factors can be difficult to ascertain, potentially leading to uncertainties in PNEC values. PNECs are often determined using models. When using models for predicting the behavior of substances in the environment, uncertainties may arise as models may not accurately account for all factors affecting the behavior of substances in a given environment. For emerging contaminants, sufficient toxicological data are not always available for a robust PNEC value determination. In such cases, it can be difficult to determine a safe level of exposure in the environment.

Another uncertainty lies in the unclear interaction between individual substances. PNEC values are determined for individual substances and do not provide information on how these substances may interact with other substances in the environment. In ecotoxicology, the interactions of CECs are addressed by the expression of mixture effects [28–30].

Comparison with other studies

The grey water footprint of pharmaceuticals and other CECs in wastewater has so far only been addressed by a few studies [17–19]. However, the aforementioned studies quantified the total GWF, while this study focuses on the GWF of a unit volume of wastewater discharged. A direct comparison of values is thus not possible. Nevertheless, it is possible to compare whether substances monitored in previous studies are also significant CECs according to the results of this study. Martínez-Alcalá et al. [19] focused solely on the four most common pharmaceuticals (Carbamazepine, Diclofenac, Ketoprofen, and Naproxen). Similar to our study, Martínez-Alcalá et al. [19] identified Carbamazepine and Diclofenac as more risky/dangerous/hazardous contaminants. In the study by Wöhler et al. [17], the highest GWF was caused by the Ethinylestradiol hormone, which was not detected in wastewater during JDS4. The main reason for the highest GWF of Ethinylestradiol refers to its extremely low PNEC value (0.00001 µg/L), used in the study by Wöhler et al. [17]. Oxazepam (anti-anxiety and depression medication) was identified as a substance with the second-highest GWF in the Netherlands but was not considered as potentially risky in this study. The reason is the use of very different PNEC values; in our study, a value of 0.37 µg/L was used, while in the study by Wöhler et al. [17], a value of 0.0019 µg/L was used. In contrast, Diclofenac had the second-highest GWF in Germany, which corresponds to the findings in our study, which also ranks Diclofenac among risky substances in terms of grey water footprint.

The GWF of a unit volume determined according to Equation 1 corresponds to the Risk Quotient (RQ) defined as the ratio between PEC and PNEC when applied to wastewater. Usually, RQ is applied to water bodies, such as rivers, lakes, and reservoirs. In some cases it has also been applied to wastewater, as in the study by Chiffre et al. [31] where the highest risk quotients refer to the antibiotics Sulfamethoxazole and Ofloxacin. Ofloxacin was not detected in wastewater at monitored WWTPs during JDS4. Sulfamethoxazole was found in wastewater during JDS4, but the GWF values (alias risk quotient) were very low, and therefore, it was not identified as potentially risky in this study. The difference between these two studies is due to the very different PNEC values for Sulfamethoxazole, which are 0.6 µg/L (this study) and 0.027 µg/L in the study by Chiffre et al. [31]. Similarly, large differences in PNEC values can be found for two other substances, Diclofenac and Ciprofloxacin, which were investigated in both compared studies. For the other monitored substances, these two studies do not overlap. This highlights the great importance of using the most reliable PNEC values based on the most recent findings, as scientific knowledge in the field of PNEC is currently rapidly evolving in relation to the attention paid by society to emerging contaminants.

Another study that dealt with the RQ of emerging contaminants in wastewater is a relatively recent Egyptian study [32]. In this work, Ampicillin, Diclofenac, and Sulfamethoxazole are identified as substances with the highest risk quotient. All these substances were found in wastewater during JDS4, but only Diclofenac was considered as potentially risky. The Egyptian study does not provide the source of the PNEC values used, but comparing the amounts of particular substances in discharged wastewater, it is apparent that effluent concentrations were 1–3 orders of magnitude higher than the maximum concentrations detected in WWTP effluents within JDS4. This implies that the amounts of these emerging contaminants discharged via treated wastewater may depend on various factors. One factor is the technological equipment of wastewater treatment plants and their ability to remove these substances. Other factors include climatic and operational conditions [33]. Another significant factor is the presence of emerging contaminants in WWTPs influents, which is influenced by a character of a sewerage-drained area, population characteristics, social and healthcare habits, etc. [34]. For example, CEC concentrations in untreated wastewater tend to be higher in the Asian region than in Europe or North America [35].

Screening vs. long-term data

Data obtained during JDS4 represent short-term wastewater monitoring. However, the variability of CECs in wastewater is subject to seasonal [36, 37] and daily dynamics. Daily dynamics can be suppressed by taking 24-hour composite samples. Seasonal dynamics cannot be captured by the screening measurements within JDS4. A very interesting insight into the CEC seasonal dynamics in wastewater is provided by a recently published study of two WWTPs in Ireland [38], where most of the monitored CECs showed high variability throughout the year. Given that the published data do not show a clear dependence on the season and often fluctuate randomly in individual measurements, it can be assumed that these data also reflect short-term variability caused by a range of other factors.

Grey water footprint of sludge management

In this study, we did not address the issue of CEC entry into the aquatic environment via sludge dewatering and land application, although it is one of the significant sources [39–41]. Currently, there is no sufficient data to quantify CEC entry from sludge management into the aquatic environment.

CONCLUSION

This study focused on the significance of particular CECs detected in wastewater within the fourth Joint Danube Survey (JDS4). With regard to the objectives of the study – determining the significance of individual substances – the grey water footprint of a unit volume of wastewater was determined (i.e. not the total grey water footprint). Telmisartan, used to treat high blood pressure, has been tagged as the most problematic substance; this is mainly due to relatively high concentrations detected in wastewater and the very low PNEC value. Comparing the results of this study with other studies highlights the main issues that such studies currently have to face. The first issue is the selection of PNEC values. For particular CECs, very different PNEC values can be found in the literature, which can differ by several orders of magnitude. The second issue is the selectivity of most studies, which usually include only a selection of a few CECs. From this point of view, JDS4 provided a unique dataset, even though it only covered 11 selected WWTPs in the Danube river basin. However, the available data did not allow an assessment of absolute significance, for which it is necessary to know the total amount of particular CECs in the wastewater monitored, not just the maximum and minimum concentrations.

Literature

[1] RATHI, B. S., KUMAR, P. S., SHOW, P.-L. A Review on Effective Removal of Emerging Contaminants from Aquatic Systems: Current Trends and Scope for Further Research. *Journal of Hazardous Materials* [on-line]. 2021, 409, 124413. ISSN 0304-3894. Available from: doi: 10.1016/j.jhazmat.2020.124413

[2] NĚMEJCOVÁ, D., HUDCOVÁ, H., BEDĚRKOVÁ, I. Společný průzkum Dunaje 4 – největší mezinárodní říční expedice roku 2019 se blíží. *Vodohospodářské technicko-ekonomické informace* [on-line]. 2019, 61(2), pp. 50–51. ISSN 0322–8916, 1805-6555. Available from: https://www.vtei.cz/2019/04/spolecny-pruzkum-dunaje-4-nejvetsi-mezinarodni-ricni-expedice-roku-2019-se-blizi/

[3] NG, K., ALYGIZAKIS, N., NIKA, M.-C., GALANI, A., OSWALD, P., OSWALDOVA, M., ČIRKA, Ľ., KUNKEL, U., MACHERIUS, A., SENGL, M., MARIANI, G., TAVAZZI, S., SKEJO, H., GAWLIK, B. M., THOMAIDIS, N. S., SLOBODNIK, J. Wide-Scope Target Screening Characterization of Legacy and Emerging Contaminants in the Danube River Basin by Liquid and Gas Chromatography Coupled with High-Resolution Mass Spectrometry [on-line]. *Water Research*. 2023, 230, 119539. ISSN 0043-1354. Available from: doi: 10.1016/j.watres.2022.119539

[4] HOEKSTRA, A.Y., CHAPAGAIN, A. K., ALDAYA, M. M., MEKONNEN, M. M. *The Water Footprint Assessment Manual: Setting the Global Standard*. London; Washington, DC: Earthscan, 2011. ISBN 978-1-84971-279-8.

[5] HOEKSTRA, A.Y., HUNG, P. Q. *Virtual Water Trade – A Quantification of Virtual Water Flows between Nations in Relation to International Crop Trade*. 12. Delft, The Netherlands: UNESCO-IHE Institute for Water Education, 2002. Value of Water Research Report Series. Available from: https://waterfootprint.org/media/downloads/Report11_1.pdf

[6] ANSORGE, L., STEJSKALOVÁ, L. Citation Accuracy: A Case Study on Definition of the Grey Water Footprint [on-line]. *Publications*. 2023, 11(1), p. 8. ISSN 2304-6775. Available from: doi: 10.3390/publications11010008

[7] ENE, S.-A., TEODOSIU, C. Grey Water Footprint Assessment of the Wastewater Treatment Plants in the Prut-Bârlad Catchment. *Buletinul Institutului Politehnic din Iaşi. Chimie şi inginerie chimică*. 2011, LVII (LXI)(2), pp. 127–143. ISSN 0254-7104.

[8] GÓMEZ-LLANOS, E., DURÁN-BARROSO, P., MATÍAS-SÁNCHEZ, A. Management Effectiveness Assessment in Wastewater Treatment Plants through a New Water Footprint Indicator [on-line]. *Journal of Cleaner Production*. 2018, 198, pp. 463–471. ISSN 0959-6526. Available from: doi: 10.1016/j.jclepro.2018. 07. 062

[9] GU, Y., DONG, Y., WANG, H., KELLER, A., XU, J., CHIRAMBA, T., LI, F. Quantification of the Water, Energy and Carbon Footprints of Wastewater Treatment Plants in China Considering a Water–Energy Nexus Perspective [on-line]. *Ecological Indicators*. 2016, 60, pp. 402–409. ISSN 1470-160X. Available from: doi: 10.1016/j.ecolind.2015. 07. 012

[10] ANSORGE, L., STEJSKALOVÁ, L., DLABAL, J., ČEJKA, E. Wpływ oczyszczalni ścieków na redukcję zanieczyszczeń odprowadzanych w czeskiej części dorzecza Odry [on-line]. *Scientific Review Engineering and Environmental Sciences*. 2020, 29(2), pp. 123–135. ISSN 1732-9353. Available from: doi: 10.22630/PNIKS.2020. 29. 2.11

[11] STEJSKALOVÁ, L., ANSORGE, L., KUČERA, J., ČEJKA, E. Role of Wastewater Treatment Plants in Pollution Reduction: Evaluated by Grey Water Footprint Indicator [on-line]. *Scientific Review Engineering and Environmental Studies*. 2022, 31(1), pp. 26–36. ISSN 2543-7496. Available from: doi: 10.22630/srees.2313

[12] GÓMEZ-LLANOS, E., MATÍAS-SÁNCHEZ, A., DURÁN-BARROSO, P. Wastewater Treatment Plant Assessment by Quantifying the Carbon and Water Footprint [on-line]. *Water*. 2020, 12(11), 3204. ISSN 2073-4441. Available from: doi: 10.3390/w12113204

[13] YAN, F., KANG, Q., WANG, S., WU, S., QIAN, B. Improved Grey Water Footprint Model of Noncarcinogenic Heavy Metals in Mine Wastewater [on-line]. *Journal of Cleaner Production*. 2021, 284, 125340. ISSN 0959-6526. Available from: doi: 10.1016/j.jclepro.2020.125340

[14] SARAIVA, A., RODRIGUES, G., MAMEDE, H., SILVESTRE, J., DIAS, I., FELICIANO, M., OLIVEIRA E SILVA, P., OLIVEIRA, M. The Impact of the Winery's Wastewater Treatment System on the Winery Water Footprint [on-line]. *Water Science and Technology*. 2019, 80(10), pp. 1823–1831. ISSN 0273-1223. Available from: doi: 10.2166/wst.2019.432

[15] JOHNSON, M. B., MEHRVAR, M. An Assessment of the Grey Water Footprint of Winery Wastewater in the Niagara Region of Ontario, Canada [on-line]. *Journal of Cleaner Production*. 2019, 214, pp. 623–632. ISSN 0959-6526. Available from: doi: 10.1016/j.jclepro.2018. 12. 311

[16] HUANG, Y., ZHOU, B., HAN, R., LU, X., LI, S., LI, N. China's Industrial Gray Water Footprint Assessment and Implications for Investment in Industrial Wastewater Treatment [on-line]. *Environmental Science and Pollution Research*. 2020, 27(7), pp. 7188–7198. ISSN 1614-7499. Available from: doi: 10.1007/s11356-019-07405-y

[17] WÖHLER, L., NIEBAUM, G., KROL, M., HOEKSTRA, A. Y. The Grey Water Footprint of Human and Veterinary Pharmaceuticals [on-line]. *Water Research X*. 2020, 7, 100044. ISSN 2589-9147. Available from: doi: 10.1016/j.wroa.2020.100044

[18] WÖHLER, L., BROUWER, P., AUGUSTIJN, D. C. M., HOEKSTRA, A. Y., HOGEBOOM, R. J., IRVINE, B., LÄMMCHEN, V., NIEBAUM, G., KROL, M. S. An Integrated Modelling Approach to Derive the Grey Water Footprint of Veterinary Antibiotics [on-line]. *Environmental Pollution*. 2021, 288, 117746. ISSN 0269-7491. Available from: doi: 10.1016/j.envpol.2021.117746

[19] MARTÍNEZ-ALCALÁ, I., PELLICER-MARTÍNEZ, F., FERNÁNDEZ-LÓPEZ, C. Pharmaceutical Grey Water Footprint: Accounting, Influence of Wastewater Treatment Plants and Implications of the Reuse [on-line]. *Water Research*. 2018, 135, pp. 278–287. ISSN 0043-1354. Available from: doi: 10.1016/j.watres.2018. 02. 033

[20] ECB. *Technical Guidance Document on Risk Assessment – Part II* [on-line]. B. m.: European Commission – Joint Research Centre Institute for Health and Consumer Protection European Chemicals Bureau (ECB), 2003. Available from: https://echa.europa.eu/documents/10162/987906/tgdpart2_2ed_en.pdf/

[21] LEI, B. L., HUANG, S. B., JIN, X. W., WANG, Z. Deriving the Aquatic Predicted No-Effect Concentrations (PNECs) of Three Chlorophenols for the Taihu Lake, China. *Journal of Environmental Science and Health, Part A* [on-line]. 2010, 45(14), pp. 1823–1831. ISSN 1093-4529. Available from: doi: 10.1080/10934529.2010.520495

[22] BELDEN, J. Chapter 28 – Introduction to Ecotoxicology. In: POPE, C. N., LIU, J. (eds.). *An Introduction to Interdisciplinary Toxicology* [on-line]. B. m.: Academic Press, 2020, pp. 381–393. ISBN 978-0-12-813602-7. Available from: doi: 10.1016/B978-0-12-813602-7.00028-4

[23] FOX, D. R., VAN DAM, R. A., FISHER, R., BATLEY, G. E., TILLMANNS, A. R., THORLEY, J., SCHWARZ, C. J., SPRY, D. J., MCTAVISH, K. Recent Developments in Species Sensitivity Distribution Modeling. *Environmental Toxicology and Chemistry* [on-line]. 2021, 40(2), pp. 293–308. ISSN 1552-8618. Available from: doi: 10.1002/etc.4925

[24] JIN, X., ZHA, J., XU, Y., GIESY, J. P., RICHARDSON, K. L., WANG, Z. Derivation of Predicted No Effect Concentrations (PNEC) for 2,4,6-trichlorophenol Based on Chinese Resident Species [on-line]. *Chemosphere*. 2012, 86(1), pp. 17–23. ISSN 0045-6535. Available from: doi: 10.1016/j.chemosphere.2011. 08. 040

[25] FIGUIÈRE, R., WAARA, S., AHRENS, L., GOLOVKO, O. Risk-Based Screening for Prioritisation of Organic Micropollutants in Swedish Freshwater [on-line]. *Journal of Hazardous Materials*. 2022, 429, 128302. ISSN 03043894. Available from: doi: 10.1016/j.jhazmat.2022.128302

[26] ZHOU, S., DI PAOLO, C., WU, X., SHAO, Y., SEILER, T.-B., HOLLERT, H. Optimization of Screening-Level Risk Assessment and Priority Selection of Emerging Pollutants – The Case of Pharmaceuticals in European Surface Waters [on-line]. *Environment International*. 2019, 128, pp. 1–10. ISSN 0160-4120. Available from: doi: 10.1016/j.envint.2019. 04. 034

[27] DULIO, V., KOSCHORRECK, J., VAN BAVEL, B., VAN DEN BRINK, P., HOLLENDER, J., MUNTHE, J., SCHLABACH, M., AALIZADEH, R., AGERSTRAND, M., AHRENS, L., ALLAN, I., ALYGIZAKIS, N., BARCELO', D., BOHLIN-NIZZETTO, P., BOUTROUP, S., BRACK, W., BRESSY, A., CHRISTENSEN, J. H., CIRKA, L., COVACI, A., DERKSEN, A., DEVILLER, G., DINGEMANS, M. M. L., ENGWALL, M., FATTA-KASSINOS, D., GAGO-FERRERO, P., HERNÁNDEZ, F., HERZKE, D., HILSCHEROVÁ, K., HOLLERT, H., JUNGHANS, M., KASPRZYK-HORDERN, B., KEITER, S., KOOLS, S. A. E., KRUVE, A., LAMBROPOULOU, D., LAMOREE, M., LEONARDS, P., LOPEZ, B., LÓPEZ DE ALDA, M., LUNDY, L., MAKOVINSKÁ, J., MARIGÓMEZ, I., MARTIN, J. W., MCHUGH, B., MIÈGE, C., O'TOOLE, S., PERKOLA, N., POLESELLO, S., POSTHUMA, L., RODRIGUEZ-MOZAZ, S., ROESSINK, I., ROSTKOWSKI, P., RUEDEL, H., SAMANIPOUR, S., SCHULZE, T., SCHYMANSKI, E. L., SENGL, M., TARÁBEK, P., TEN HULSCHER, D., THOMAIDIS, N., TOGOLA, A., VALSECCHI, S., VAN LEEUWEN, S., VON DER OHE, P., VORKAMP, K., VRANA, B., SLOBODNIK, J. The NORMAN Association and the European Partnership for Chemicals Risk Assessment (PARC): Let's Cooperate [on-line]! *Environmental Sciences Europe*. 2020, 32(1), 100. ISSN 2190-4715. Available from: doi: 10.1186/s12302-020-00375-w

[28] BARATA, C., BAIRD, D. J., NOGUEIRA, A. J. A., SOARES, A. M. V. M., RIVA, M. C. Toxicity of Binary Mixtures of Metals and Pyrethroid Insecticides to Daphnia Magna Straus. Implications for Multi-Substance Risks Assessment [on-line]. *Aquatic Toxicology*. 2006, 78(1), pp. 1–14. ISSN 0166-445X. Available from: doi: 10.1016/j.aquatox.2006. 01. 013

[29] GINEBREDA, A., KUZMANOVIC, M., GUASCH, H., DE ALDA, M. L., LÓPEZ-DOVAL, J. C., MUÑOZ, I., RICART, M., ROMANÍ, A. M., SABATER, S., BARCELÓ, D. Assessment of Multi-Chemical Pollution in Aquatic Ecosystems Using Toxic Units: Compound Prioritization, Mixture Characterization and Relationships with Biological Descriptors [on-line]. *Science of the Total Environment*. 2014, 468–469, pp. 715–723. ISSN 0048-9697. Available from: doi: 10.1016/j.scitotenv.2013. 08. 086

[30] BACKHAUS, T., FAUST, M. Predictive Environmental Risk Assessment of Chemical Mixtures: A Conceptual Framework [on-line]. *Environmental Science & Technology*. 2012, 46(5), pp. 2564–2573. ISSN 0013-936X. Available from: doi: 10.1021/es2034125

[31] CHIFFRE, A., DEGIORGI, F., BULETÉ, A., SPINNER, L., BADOT, P.-M. Occurrence of Pharmaceuticals in WWTP Effluents and their Impact in a Karstic Rural Catchment of Eastern France [on-line]. *Environmental Science and Pollution Research*. 2016, 23(24), pp. 25427–25441. ISSN 1614-7499. Available from: doi: 10.1007/s11356-016-7751-5

[32] BADAWY, M. I., EL-GOHARY, F. A., ABDEL-WAHED, M. S., GAD-ALLAH, T. A., ALI, M. E. M. Mass Flow and Consumption Calculations of Pharmaceuticals in Sewage Treatment Plant with Emphasis on the Fate and Risk Quotient Assessment [on-line]. *Scientific Reports*. 2023, 13(1), 3500. ISSN 2045-2322. Available from: doi: 10.1038/s41598-023-30477-3

[33] RODRIGUEZ-NARVAEZ, O. M., PERALTA-HERNANDEZ, J. M., GOONETILLEKE, A., BANDALA, E. R. Treatment Technologies for Emerging Contaminants in Water: A Review [on-line]. *Chemical Engineering Journal*. 2017, 323, pp. 361–380. ISSN 1385-8947. Available from: doi: 10.1016/j.cej.2017. 04. 106

[34] HAWASH, H. B., MONEER, A. A., GALHOUM, A. A., ELGARAHY, A. M., MOHAMED, W. A. A., SAMY, M., EL-SEEDI, H. R., GABALLAH, M. S., MUBARAK, M. F., ATTIA, N. F. Occurrence and Spatial Distribution of Pharmaceuticals and Personal Care Products (PPCPs) in the Aquatic Environment, their Characteristics, and Adopted Legislations [on-line]. *Journal of Water Process Engineering*. 2023, 52, 103490. ISSN 2214-7144. Available from: doi: 10.1016/j.jwpe.2023.103490

[35] TRAN, N. H., REINHARD, M., GIN, K.Y.-H. Occurrence and Fate of Emerging Contaminants in Municipal Wastewater Treatment Plants from Different Geographical Regions. A Review [on-line]. *Water Research*. 2018, 133, pp. 182–207. ISSN 0043-1354. Available from: doi: 10.1016/j.watres.2017. 12. 029

[36] CASTIGLIONI, S., BAGNATI, R., FANELLI, R., POMATI, F., CALAMARI, D., ZUCCATO, E. Removal of Pharmaceuticals in Sewage Treatment Plants in Italy [on-line]. *Environmental Science & Technology*. 2006, 40(1), pp. 357–363. ISSN 0013-936X. Available from: doi: 10.1021/es050991m

[37] ČESEN, M., HEATH, D., KRIVEC, M., KOŠMRLJ, J., KOSJEK, T., HEATH, E. Seasonal and Spatial Variations in the Occurrence, Mass Loadings and Removal of Compounds of Emerging Concern in the Slovene Aqueous Environment and Environmental Risk Assessment [on-line]. *Environmental Pollution*. 2018, 242, pp. 143–154. ISSN 0269-7491. Available from: doi: 10.1016/j.envpol.2018. 06. 052

[38] RAPP-WRIGHT, H., REGAN, F., WHITE, B., BARRON, L. P. A Year-Long Study of the Occurrence and Risk of over 140 Contaminants of Emerging Concern in Wastewater Influent, Effluent and Receiving Waters in the Republic of Ireland. *Science of the Total Environment* [on-line]. 2023, 860, 160379. ISSN 0048-9697. Available from: doi: 10.1016/j.scitotenv.2022.160379

[39] SAIDULU, D., GUPTA, B., GUPTA, A. K., GHOSAL, P. S. A Review on Occurrences, Eco-Toxic Effects, and Remediation of Emerging Contaminants from Wastewater: Special Emphasis on Biological Treatment Based Hybrid Systems [on-line]. *Journal of Environmental Chemical Engineering*. 2021, 9(4), 105282. ISSN 2213-3437. Available from: doi: 10.1016/j.jece.2021.105282

[40] ASTUTI, M. P., NOTODARMOJO, S., PRIADI, C. R., PADHYE, L. P. Contaminants of Emerging Concerns (CECs) in a Municipal Wastewater Treatment Plant in Indonesia [on-line]. *Environmental Science and Pollution Research*. 2023, 30(8), pp. 21512–21532. ISSN 1614-7499. Available from: doi: 10.1007/s11356-022-23567-8

[41] LAPWORTH, D. J., BARAN, N., STUART, M. E., WARD, R. S. Emerging Organic Contaminants in Groundwater: A Review of Sources, Fate and Occurrence. *Environmental Pollution* [on-line]. 2012, 163, pp. 287–303. ISSN 0269-7491. Available from: doi: 10.1016/j.envpol.2011. 12. 034

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Ing. Libor Ansorge, Ph.D., has been an employee of TGM WRI since 2011, and since 2018 he has been acting as Deputy director for research and professional activities. In 1997, he completed his engineering studies at the Faculty of Civil Engineering of the Czech Technical University in Prague, majoring in Water Management and Water Structures; in 2017, at the same faculty, he completed a doctoral study programme in the field of Environmental Engineering. Professionally, he deals with a wide range of issues related to water use, focusing on the future water needs of society and on the environmental assessment of water use. As a principal investigator or a research team member, he has participated in the implementation of several research projects.

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After studying hydrobiology at the Faculty of Science of Charles University in Prague, for several years, Mgr. Daniel Fiala devoted himself to the chronobiology and ecophysiology of cyanobacteria and algae at the Botanical Institute of the Academy of Sciences of the Czech Republic in Třeboň. The South Bohemian centre of his research was mainly the Lužnice floodplain, but also the local ponds and wetlands. In TGM WRI, he has been dealing with the issue of eutrophication of surface waters since 2004, focusing on the key role of phosphorus in aquatic ecosystems (especially phosphorus pollution) throughout the Czech Republic.

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Ing. Miloš Rozkošný, Ph.D., graduated from the Faculty of Civil Engineering at Brno University of Technology in the field of Water Management and Water Management Constructions. Since 2000, he has been employed at TGM WRI Brno branch in the water quality protection department as a researcher; in 2010 he became the head of the water quality protection department. He is a graduate of the certified Sampling Course for the staff of water management laboratories and control laboratories from 2000 and 2019. He has been an active member of CzWA since 2011. He mainly deals with the issues of eliminating wastewater pollution from small point sources of pollution (up to 2,000 EO), the use of natural technologies for wastewater treatment, and the treatment of polluted surface water and runoff. He also deals with the issue of comprehensive monitoring and evaluation of the status and quality of water, water and wetland ecosystems, and small water reservoirs.

Interview with Ing. Tomáš Fojtík, director of the T. G. Masaryk Water Research Institute

He has been Director of TGM WRI for a year. How does he evaluate this first year and what has he already managed to change for the better in our Institute? How does he remember his twenty years at the Institute as regular employee? And what are his plans and goals for the future regarding the direction of TGM WRI? „I would like to continue fulfilling my vision of creating a recognized and functioning institute of national and European importance as a research base for the field of water management with such a working culture and environment that it would be a target and prestigious workplace for quality and satisfied experts willing to actively cooperate," says the Director of our Institute, and newly also the president of the International Commission for the Protection of the Elbe, Ing. Tomáš Fojtík.

Mr. Director, allow me to start with a usual question. Do you remember the moment when water first appealed to you so much that you decided to dedicate your professional life to it?

I don't remember the specific moment. It is probably due to the fact that we are used to taking water for granted. I believe this approach is not good. Water is one of the most precious „things" we need and we should treat it accordingly, value it and take proper care of it. The work at our Institute opened my eyes even more in this regard, and thanks to it I began to perceive the importance of protecting water and the aquatic environment much more intensively.

You have been working at T. G. Masaryk Water Research Institute since 2004. Do you remember your beginnings and your first project?

I joined TGM WRI in the GIS and cartography department, where there was a wonderful team – I spent great times there that I would like to thank my colleagues for. One of the first projects I worked on and which I subsequently led was the collaboration with the Land Surveying Office and the Czech Hydrometeorological Institute on the creation and updating of ZABAGED®, specifically the geometry and numbering of watercourses, water bodies, and catchment boundaries. This long-term project, which continues to this day with other activities, showed me, among other things, how important quality and guaranteed data are and, above all, cooperation, without which it would be difficult to achieve the desired goals in water protection. The activities of the GIS and cartography department are intertwined with the activities of most branches of our Institute. Thanks to this, I came into contact with a wide range of implemented projects, and thus had a unique opportunity to get to know the entire scope of our organization. This experience helps me a lot in my current position.

You have completed your first year as Director of TGM WRI. How would you rate your year at this institution? Did it meet your expectations?

Rather, I ask myself whether I have fulfilled the expectations of my colleagues both inside and outside our Institute. Of course you have to ask them about that. I try to do everything to make my colleagues happy and our organization to flourish. We are only at the beginning of the journey. When I became Director a year ago, I found a lot more, shall we say „challenges" than I expected. I started working immediately and believe me, it was not an easy year. But I could never do it all by myself. Success and progress would not have occurred if it were not for great colleagues who want to move our Institute forward. Many thanks to all of you for your joint efforts!

Do you consider your long-term work at TGM WRI as an advantage, or rather as a disadvantage?

Certainly as an advantage, BUT... During the more than twenty years at TGM WRI, I had the opportunity to get to know in depth its functioning, activities, people, but also areas that did not function quite as they should. For the position of Director, this is essential for understanding the organization and subsequent quality management. The above-mentioned „BUT" hides the need to maintain sufficient perspective, impartiality, and distance. Which is very important, but also difficult. However, it cannot be done without it. I dare to say that I succeeded, although it was not always easy and painless. From this position, I would like to give back to the Institute and the people in it everything that they gave me… in a good way :-).

Where do you think TGM WRI should go and what are your goals and plans for the future?

I would like to continue fulfilling my vision of creating a recognized and functioning Institute of national and European importance as a research base for the field of water management, with such a working culture and environment that it would be a target and prestigious workplace for quality and satisfied experts willing to actively cooperate. Even though many things have already been set up correctly and changed for the better, we are still at the beginning of the journey, which will definitely not be easy, but I believe that we will manage it together.

It is absolutely necessary to continue to stabilize and strengthen the teams, to ensure decent financing and, above all, to provide high-quality and independent solutions not only for scientific and research projects. The role of our Institute as a departmental research institution is also key and unique. Thanks to our more than a century-old tradition and the experience of our employees, we can comprehensively grasp the contemporary fundamental topics in the field of water protection and water-bound species, water and waste management, climate change, hydrology, hydrogeology, but also geoinformatics and data management and publication. Subsequent outputs from the nature of departmental research are therefore not only publication ones, but primarily application ones, so that they are of practical and usable benefit, above all to the general public, a founder, or other providers or contractors. I would also like to invite everyone who is interested in getting to know our work to the Open Day, which will take place in June 2024.

Since the first of January this year, you have become the President of the International Commission for the Protection of the Elbe. Were you surprised by this offer?

I was very pleasantly surprised by this offer and I appreciate it very much. The position of President of the International Commission for the Protection of the Elbe is not only prestigious, but also important. At the same time, however, it is a huge responsibility and an opportunity to participate in improving not only the state of watercourses, but also to contribute to a better environment for future generations. Our Institute, or rather my colleagues, have been members of expert groups and working groups, their spokespersons, or even their chairmen. In this way, we participate in many activities of the Commission and the formulation of strategic documents, such as the International Management Plan for the Elbe River Basin District and the International Flood Risk Management Plan for the Elbe River Basin District.

Is there a specific topic that you would like to focus on as the president of the International Commission for the Protection of the Elbe?

I would like to focus on strengthening international cooperation and joint cross-border projects that will have a real impact on water quality. As water knows no borders, international cooperation is very important. I greatly appreciate the work of my colleagues from neighbouring countries and look forward to working with them as well as with Czech partners within the framework of the ICPER.

However, I think I have talked enough, and as they say – let's work, and not just write about it :-).

Director, thank you very much for your time.

Ing. Josef Nistler

Ing. Tomáš Fojtík

Ing. Tomáš Fojtík, born on 2nd December 1981 in Prague, graduated from the Faculty of Economics and Management at the Czech University of Life Sciences in Prague. Here, in 2008, he obtained a bachelor's degree, and in 2011, an engineer's degree. He has been working at TGM WRI, p. r. i., since 2004, initially as a researcher in the GIS and cartography department. One of his first projects, in which he participated and subsequently led, was cooperation with the Land Surveying Office and the Czech Hydrometeorological Institute on the creation and updating of ZABAGED®, specifically the geometry and numbering of watercourses, water bodies, and catchment boundaries. In 2015, he became the head of this research department. On 1st February 2023, he was appointed to the position of Director of TGM WRI, p. r. i. On 1st January 2024, he also became the President of the International Commission for the Protection of the Elbe.

Current research at TGM WRI on municipal biodegradable waste and food waste

Since 2021, research on selected issues related to the collection, sorting, processing, and reuse of selected types of biodegradable waste has been carried out at TGM WRI within the „Centre of Environmental Research: Waste management, circular economy and environmental security" (CEVOOH), which was supported as part of the call of the Technology Agency of the Czech Republic „Environment for life", Subprogramme 3 „Long-term environmental and climate perspectives", for the period 2021–2026. The research follows on from a number of partial research projects and tasks, an overview of which can be found, for example, on the HEIS WRI website [1] under the Projects tab.

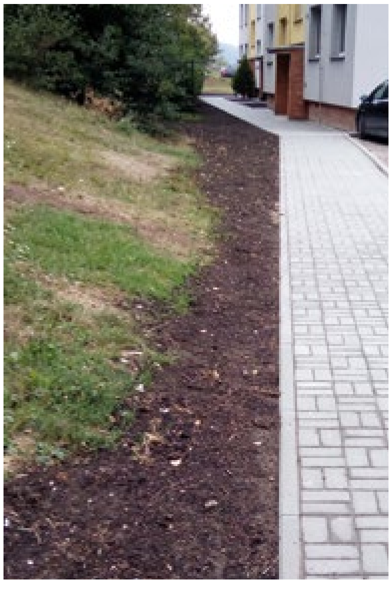
Specifically, it is a work package of the Centre labelled WP 1C „Biodegradable waste". Its purpose is to contribute to increasing awareness regarding the management of biodegradable waste from households, municipalities and cities, including sewage sludge and specific types of food waste, and to deal with the possibilities of their processing (e.g., composting) and other modifications for their recycling (production of substrates for agriculture, green areas of the inner city, etc.). It can be expected that the summary of research results, examples of good practice, and challenges for further improvement will complement the range of already available materials and give an easily accessible overview of these resources. More detailed information can already be found on the CEVOOH project website [2] and the work package WP 1C webpage [3], where electronic versions of the outputs will gradually be published.

Currently there are, for example, materials from the first workshops held in 2022 on the following topics:
- Processing of biowaste by composting and application of composts in agriculture and maintenance of urban green areas
- New procedures and methods of food waste prevention

The first of them presented partial results of research regarding the benefits of adding organic matter to the soil, including compost. The possibility of recycling biodegradable waste and returning organic matter to the natural cycle (especially through composting) has the potential to improve soil retention capacity and therefore deserves attention. Drought periods accompanied by torrential rain increase the influence of water and wind erosion on soils, thereby reducing water supply for agricultural crops as well as for urban green vegetation. Water erosion leads to the degradation of the soil profile (mainly topsoil), so it is necessary to protect the soil surface from being washed away. The importance of organic fertilization depends on its quality, quantity, and method of incorporation into the soil, which affect the physical, chemical, and biological properties of the soil, and thus the nutrient status needed for plant growth. Due to the low content of organic substances, the physical properties of soils deteriorate, leading to a deterioration in rainwater absorption and its insufficient retention in the soil. Research also points to the benefit of applying compost and organic matter for the moisture and temperature conditions in the immediate environment, thanks to better moisture retention.

The workshop also presented the results of research on different types of composts according to their origin, ranging from composts from green areas of small villages to market products of large compost plants. The results clearly show that each of these compost types has a positive effect on improving soil properties and water retention. However, it is necessary to consider that the main effect can be manifested only after a longer application period. The researchers also presented experience with the use of composts for the maintenance of green areas in an urbanized environment, especially in towns and villages, practical experience with the application of composts as part of substrates for green roofs and facades, and as fertilizers for residential greenery. Variations in the effect of different types of compost on increasing water retention by green roofs, supporting the growth and improving the quality of grasslands, increasing soil fertility, etc., were also shown.

As part of the workshop „Food waste – possibilities of using prevention approaches", ideas were presented that need to be considered when setting up preventive measures. These include the determination of target groups, length of time to achieve the goal, type of commodity concerned, independence and



Figs. 1–3. Examples of the use of substrates from the composting of municipal biowaste in repairing the infrastructure of settlements and green areas.

complexity of the measure, and the current state of legislation. Specific proposals for these measures were then presented in the form of information campaigns, legislative regulations, planning, methodological support, and composting. Simultaneously, the procedures for evaluating their effectiveness were presented.

In the lecture entitled „Analysis of food waste and its use", co-researchers from the Institute of Chemical Process Fundamentals of the CAS presented technologies for processing food waste, namely biogas stations, composting plants, hydrolysis, landfill, and incinerators. The pros and cons of each were discussed with regard to hygiene conditions and the spread of pathogens.

The results planned in 2023 also include two key outputs, which are methodological instructions processed in cooperation with the project guarantors from the Ministry of the Environment on the issues of „Measurement of the amount and analysis of the composition of food waste" and „Recommendations for the handling, processing, and reuse of selected biodegradable waste".

Figs. 4, 5. The use of substrates from composting biodegradable waste increases the possibilities of water retention in the soil, supports the growth of vegetation by replenishing nutrients and gradually releasing moisture.

Fig. 6. Process of composting biowaste

If you are interested in more detailed information about the project results and proposed solutions, do not hesitate to contact the authors.

Other institutions cooperating under the WP 1C work package:
- CENIA, Czech Environmental Information Agency,
- Institute of Chemical Process Fundamentals of the CAS,
- VSB – Technical University of Ostrava,
- Brno University of Technology, AdMaS centre.

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Literatura

[1] https://heis.vuv.cz/
[2] https://cevooh.cz/
[3] https://cevooh.cz/home/1-c-biologicky-rozlozitelne-odpady/

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SLUČÍ STREAM ON ČERNÁ OPAVA

Černá Opava is one of the three sources of the river Opava, together with Bílá and Střední Opava. The basin is located between the municipalities of Rejvíz and Vrbno pod Pradědem; geologically, it is on the border between Nízký and Hrubý Jeseník. There, the Palaeozoic sedimentary rocks change to more resistant metamorphic rocks; the terrain altitudes rise, the valleys deepen and become wilder, and, in the Lysý vrch and Orlík, the overall landscape character changes to montane to alpine ranges of the highest altitudes. Černá Opava got its name from the coloured water due to its contact with peatlands. Today, few people realize that in the past it was a basin with intensive use of water for powering saws and hammer mills, of which only ruins remain, such as Brandlův mlýn and Josefský hamr. These can be found in the valley; however, on the ridges you can also find the ruins of medieval castles, the most well-known being Kvinburk and Koberštejn with a relatively well-preserved castle tower. In this basin, there are also three experimental research basins operated jointly by the Czech Hydrometeorological Institute and the Forestry and Game Management Research Institute. Namely, they are the basins of Slučí, Sokolí, and Suchý streams. The photo shows a small water mill on Slučí stream near the closing profile of this research basin.

Text and photo: doc. RNDr. Jan Unucka, Ph.D.

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