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Determination of Ecological Flow for Macroinvertebrate Communities in Streams Affected by Urban Drainage – Case Study of Prague

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Abstract This article is focused on definition and identification of optimal ecological flow for macrozoobenthos communities in small urban creeks affected by urban drainage using the Physical HABitat Simulation (PHABSIM) system. It describes the process of determination of ecological flows, from field measurement to determined values. Results show that combine sewer overflows and storm water drains negatively affect urban creeks and theirs diversity. In the end it compares determined ecological flows with measured and given values. Results show that minimum ecological flows are not reached in one third of a year and determined optimal flows are not abided.

Keywords: Optimal ecological flow, diversity, ecology, flow, invertebrate, urban drainage.

INTRODUCTION

Small urban creeks are heavily influenced by human actions. The most important impacts include inlet of sewer system, reduction of pervious surface and soil column, channel modification, discharge of pollutants and water use [1]. Small urban creeks are also affected by combine sewer overflows (CSOs) and stormwater drains (SWDs). Small urban creeks are typically changed by human activities and suffer from the so-called urban creek syndrome [2].

Urban creeks suffer from rapid changes of flow between periods of very low flows and very high flows caused by inlet of a sewer system [3]. Extreme high stream flow also leads to the increase of the flow shear stress and decrease of the stability of river side and river bed. Creek channel is widening due to erosion and remains too wide for low river flow.

In recent years the main attention of scientific research community was aimed at the assessment of the interactions between water bodies, water ecosystems and the whole environment. Modern scientific research in this field was established the second part of 20th century [4]. Minimum flows were determined to ensure the water quantity in small creeks affected by human activities, such as creeks used for hydroelectric power stations or water bodies with dams. However, the assessment of minimum flows to maintain a good ecological status of the recipients was omitted for a long time. The recent Water Framework Directive (WFD) has addressed besides other things the serious impact of urban drainage on ecological quality of urban creeks and stated that is necessary to reach a good ecological condition of urban creeks [4-8].

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CONCEPT OF ECOLOGICAL FLOW

The impact of river flow on changes of aquatic ecosystems has been increasingly addressed since the middle of the last century. Minimum flow rates were defined to ensure proper management and ecological functionality of the catchments. The minimum flow was usually expressed by single value Q355d [4, 9], which means a flow that runs through 355 days in year or bigger. However, in most cases this value was insufficient for maintaining good ecological state of a small river. This has promoted further research on the identification of minimum and optimal ecological flow.

Systematic research conducted since 1983 by the German water management company LAWA (Länderarbeitsgemeingeschaft Wasser) was focused on basic questions to define threshold values in a field of low rates of flow [10]. Numerous methods developed until present times estimate the minimum rate of flow based on hydrological and hydraulic characteristics. Other approaches such as the MODM – “Multiobjective decision making” consider ecological and economical effects of a minimum rate of flow [10]. Other approach "Consideration of the interests of water withdrawals" was developed in Switzerland and takes into account factors such as public interests on water withdrawals, management interests, water supply, water quality performance, importance of a stream as a landscape component and as a living environment for fauna and flora incl. typical local vegetation [11]. The model PHABSIM was developed in 70's to determine minimum ecological flows in rivers, as a tool for quantification of relationship between physical habitat and flow from the point of view of living conditions for fishes [4, 12] and will be further described in this paper.

Ecological flow or ecological suitable range of flow are values which provide good living environment to organisms and their living phase fixed on water. Besides the minimum

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Fig. (1). The Botic creek with indicated particular sectors of interest.

rates of flow, maximum rates caused by CSOs and SWDs must be considered to assess the ecological status of an urban stream. Extreme flows change the morphology of a creek by erosion, flush away aquatic organisms and cause changes in the composition of creek biota (sensitive *vs.* tolerant species). Extreme flow also destroys natural habitats and shelters by floating the river bed material. These and other effects on streams caused by urban drainage are described elsewhere [1, 4].

The article presents a identification of the minimum, maximum and optimal ecological flow values in three urban creeks in the Prague metropolitan area (Czech Republic) affected by urban drainage. The objective of this paper is threefold: first, to compute the flow values by use of the PHABSIM approach, and second, to compare the computed values with measured flows in the selected creeks, and finally to evaluate the impact of the urban drainage systems of the spatial and temporal distribution of the ecological flow values. Such a study has not yet been performed in the Czech Republic and provides suitable methodological tools to the management of urban catchments. But it is an important step forwards the international goal given by WFD.

STUDY AREA

The study area encompasses three watersheds in the Prague metropolitan area (Czech Republic): the Botic creek and the Rokytka creek affected by CSOs and the Zatissky creek affected by SWDs.

BOTIC CREEK

The Botic creek is the largest tributary to the Vltava River in Prague with the average rate of flow 0.44 m^3/s. The creek is 34.5 km long with catchment area of 135 km^2. It emerges near a small village Krizovy Ujezdec in the altitude 475 meters a.s.l. and flows into the Vltava River at 187 meters above sea level. The Botic flows mostly through intensively used agricultural land and only a few larger forested areas. Below the Hostivar reservoir, the creek passes through a highly developed area and partly flows in a pipe. 33 combine sewer overflows run to Botic creek - 22 from the right side and 11 from the left side. Our section of interest (Fig. **1**) is located below the Hostivar reservoir between kilometers 10.719 and 12.745 of the creek's length and it is protected as a natural reservation. Two CSOs carrying water from industry areas, streets and populated areas are located in the studied section. The observed section was divided into five sectors. Every sector has two profiles, which represent characteristic morphological and hydraulic conditions of the creek.

The first sector is located above the Hostivar reservoir and is about 80 m long with a slope of 1.9 %. This sector is surrounded by alders and maples whose roots reach the creek and create suitable habitats for various invertebrate species. The second sector describes the creek below dam and is approximately 350 m long with a slope within the range of 0.2-0.8%. The creek in the second sector is meandering through hornbeams, alders and maples, changing deeper and shallower parts with different rate of flow. This sector is located above first CSO (in the drainage system identified as CSO83).

The sector affected by the CSO83 is about 700 m long, with a slope of 1.1% s, and is characterized by river floodplain covered by trees and bush. The fourth sector is located above the CSO80 over a length of about 250 m. Both sides of the creek are covered by maples, beeches and alders. They are typically affected by erosion processes. The average slope of this part is 1.6%. Finally, the fifth sector is located below the CSO80. This sector, highly affected by erosion, is approximately 300 m long with a slope of 1%.

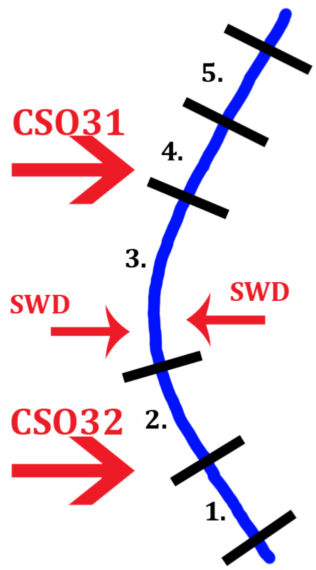


Fig. (2). The Rokytka creek with indicated particular sectors of interest.

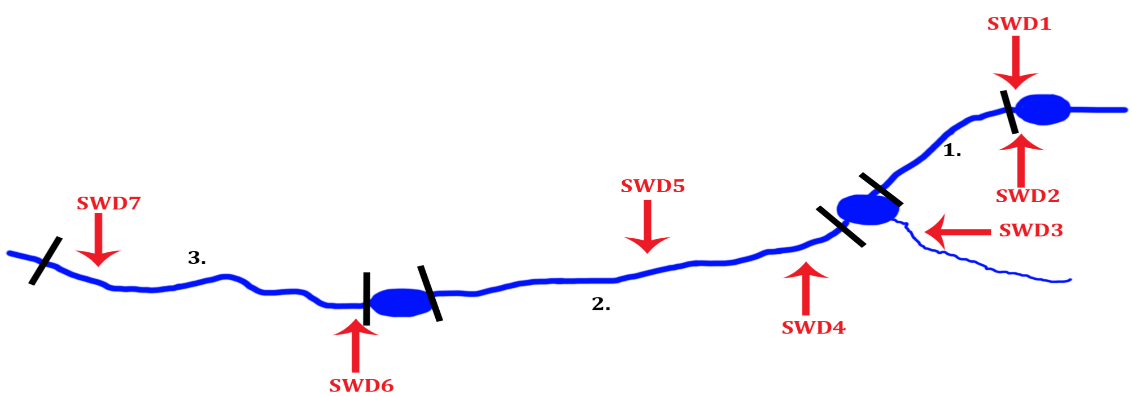


Fig. (3). The Zatissky creek with indicated particular sectors of interest.

ROKYTKA CREEK

The Rokytka creek is another tributary to the Vltava River. It's 36 km long with average rate of flow 0.39 m^3/s. On the east border of Prague the creek flows through several ponds and 15 CSOs (7 right-sided, 8 left-sided) and more than 100 SWDs discharge to the creek. The studied section of the Rokytka creek (Fig. **2**) is in the area of Prague - Hrdlorezy with a length of 1.3 km. Two combined sewer overflows (CSO32 and CSO31) and SWDs discharge to this section of the creek.

The first characteristic sector is located above the CSO32. It has a regular channel with a slope of about 0.4-0.6% and a length of 150 m. Normal water level in this sector is approximately 60 cm. This sector is characterized by low rate of flow and sedimentation of fine material.

The second sector is located below the CSO32 with a length of about 200 m and a slope of 2%. This sector has steep shores with marks of water erosion. The third sector is affected by SWD. The third sector is approximately 380 m long, with a regular trapezoid channel. The fourth and fifth sectors are both located below the CSO31 and have a trapezoid channel with a length of approximately 150 m and a slope of 1.3%. The fifth sector is affected by overflow on longer distance than fourth one.

ZATISSKY CREEK

This creek represents effect caused by SWD. The Zatissky creek (Fig. **3**) is only about 3 km long and its catchment area has 3 km^2. The stormwater inlets drain the local housing estates and have no further cleaning. For this study the Zatissky creek was observed in its whole length except for a small part in a tube. Reservoirs on Zatissky creek divide the creek into specific sectors. The first sector is 900 m long, has a slope of 0.2% and is characterized by meandering channel and very low diversity of macroinvertebrates.

The second sector passes through forest vegetation and river floodplain. The slope is between 2-5%. The channel in this sector is heavily affected by erosion and therefore morphologically different than in the first sector. An attempt was made in the 1970's to revitalize this sector, but the stream has adopted a new path almost 9m from the revitalization site. This sector is biological very poor. Finally, the third sector flows straight through a colony of gardens, has a slope of 1.2% and also the biggest diversity and abundance in the whole Zatissky creek.

METHODS

Field Work

The shape of all profiles was identified by levelling and the rate of flow was measured by standard hydrometer. River bed properties and possible shelters for target macroinvertebrate species were described during the fieldwork. The grading curve of the river bed substrate was determined in the laboratory of Department of Sanitary and Ecological Engineering on Faculty of Civil Engineering on Czech Technical University. This survey was repeated during the vegetation seasons to obtain different hydrological and hydraulic data.

Biological survey of macroinvertebrate community in every season was conducted by sampling in individual cells of the profiles to cover all types of habitat. Actual rate of flow and substrate were measured for every cell. Samples of macroinvertebrates were taken by the kicking method [13-17]. Gathered macroinvertabrates were fixed by ethyl alcohol and moved to the biological laboratory of Department of Sanitary and Ecological Engineering on Faculty of Civil Engineering on Czech Technical University for further identification. The macroinvertebrate community was selected as a target group of organisms, because the size of studied creeks does not support permanent fish population and macroinvertebrates are good indicator of aquatic ecosystem quality. Monitoring on the Botic and Rokytka creeks was conducted in the vegetation season of two consecutive years 2003 and 2004.The Zatissky creek was monitored only for one year during summer and autumn of 2003

Physical HABitat Simulation System (PHABSIM)

The “Physical HAbitat Simulation System” (PHABSIM) software was used to determine the minimum, maximum and optimal ecological flow. PHABSIM is based on the IFIM methodology (Instream Flow Incremental Methodology) [18]. This flexible methodology is typically used for determination of acceptable residual rate of flow and for projects of operating manuals. It helps to design the optimal use of a creek and minimize the ecological impact of water withdrawals. The essential advantage is that IFIM stands on real condition of a river or a creek, considers the needs of the species and changes in the stream environment. In contrast to other methods IFIM does not give only one value of the minimum residual flow but allows for optimization of the rate of flow according to the needs of specific species in different seasons [4, 18].

The PHABSIM describes the impact of the microhabitat changes with the rate of flow using the Weighted Usable Area (WUA). The WUA is an available area for different life stages of specific species and depends on rates of flow. The WUA are based on Habitat Suitability Indexes (HSI). The HSI describes the frequency of occurrence of evaluated individual species in different condition of depth, bottom sediment and rate of flow [19, 20], which are the input data measured on site. More individuals of target species (MESC - Midcontinent Ecological Sciences Center recommend at least 100 pieces) in a same life stage need to be collected for determination of the HSI [4]. PHABSIM was validated and used as a model for habitat requirements (spawning requirements) of Salmonid Fish [21, 22], it was used for estimation of fresh-water fish habitat [23] and estimation of water fisheries resources in England and Wales [24]. For this study was PHABSIM chosen for its ability to investigate habitat availability for macrozoobenthos, observe target life form, in a range of flows, different substrate and water depth.

Determination of Ecological Flow

The ecological flow was at first determined for individual macroinvertebrate species and later for the whole community of macroinvertebrates. This approach gives a possibility to identify optimal ecological flow, which will support a high biological diversity of the creek. In the case of Botic, Rokytka and Zatissky creek HSI were computed for species which exceeded the required number of individuals during every field sampling campaign and every season. Sampling profiles were divided to transects, each presenting different habitat, rate of flow, bottom sediment, and depth of water. The HSIs were computed separately for depth, sediment, flow. WUA graphs are the final output from the PHABSIM model, providing information about the range of ecological flow. The determination of minimum and maximum flow was based on the size of the surviving community guaranteeing a recovery of the community. A condition was adopted that 20% of the community needs to survive extreme flow events to provide suitable inoculums for the community recovery [25].

Determination of Diversity

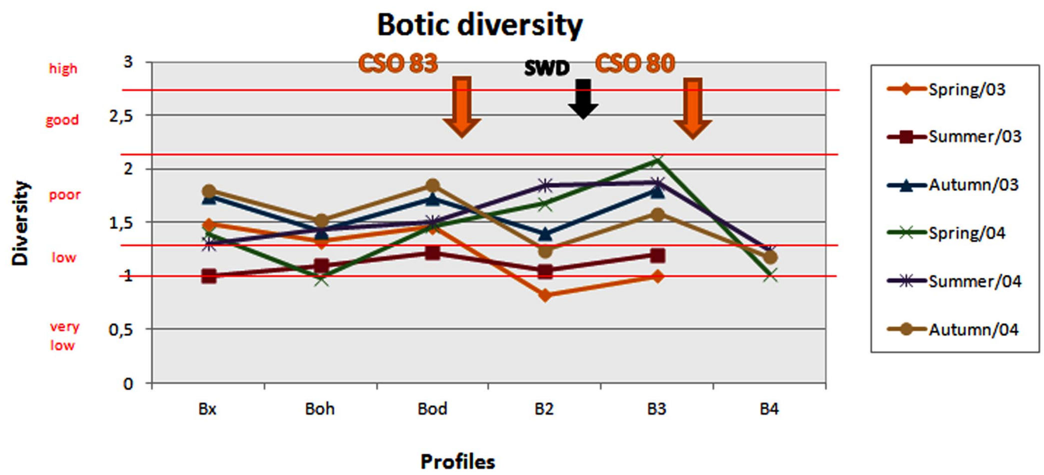
The Shannon - Weiner species diversity index H [4, 26] was used to evaluate the biological state of a creek. The diversity identification was based on kick sampling [13- 17] taken from individual cells of profiles of observed creeks during the monitored period.

RESULTS AND DISCUSSION

Botic Creek

Diversity

From 5 to 16 macroinvertebrate species were identified during an observation period in the Botic creek, resulting in a poor or low diversity index for this stream. The diversity has strongly depended on the sampling site (Graph **1**). The graph shows a high degree of similarity in the trends among different sites and seasons. This indicates a factor that steadily affects the diversity and therefore the biological status of the creek. The main explanation of the site-to-site differences is the location of the sites with low diversity (B2 and B4) below the combine sewer overflows.



Graph (1). Diversity index of the Botic creek expressed by the Shannon - Weiner species diversity index H for each monitored season [4].

Table 1. Range of ecological flows for Botic (Years 2003-2004) [4].

Creek	Q_{opt} / 03	Q_{min} / 03	Q_{max} / 03	Q_{opt} / 04	Q_{min} / 04	Q_{max} / 04
Botic - Spring	0.29 - 0.38	0.17 - 0.20	0.95 - 1.00	0.32 - 0.43	0.21 - 0.22	0.91 - 0.93
Botic - Summer	0.36 - 0.45	0.19 - 0.21	1.05 - 1.08	0.42 - 0.53	0.19 - 0.21	0.95 - 1.00
Botic - Autumn	0.38 - 0.48	0.23 - 0.24	0.95 - 0.98	0.38 - 0.48	0.22 - 0.24	0.95 - 0.99

Another profile with low diversity (B0h) was not affected by sewer system, but it is a profile with pool character with a depth up to 1.5 m with very small rate of flow. This shows that the creek morphology has a direct impact on the biological diversity. This is also is in agreement with findings in a number of other studies [4, 27- 29].

Ecological Flows

Table **1** summarizes the ecological flow rates computed by use of the PHABSIM method. It shows that each of the calculated ecological flow rates (minimum, optimal and maximum) slightly differ between the two years of study. This may be caused by changes in the benthic organism communities or in the morphology during those years or by difference in temperature during the observation period. Qopt/03 means optimal flow for year 2003; Qmin/03 means minimum flow for year 2003 and so on.

The range of ecological flows for the Botic creek are calculated as an average from the two results for 2003 and 2004 (see Table **1**) for each period: spring optimal ecological flow 0.32 - 0.38 m^3/s, spring minimum ecological flow 0.20 - 0.21 m^3/s and maximum flow 0.93 - 0.95 m^3/s. During summer period the optimal flow was in the range of 0.42 - 0.45 m^3/s, minimum flow 0.19 - 0.21 m^3/s, and maximum flow 0.95 - 0.98 m^3/s. In the autumn period the values reach 0.38 - 0.48 m^3/s for optimal, 0.19 - 0.21 m^3/s for minimum and 0.95 - 0.98 m^3/s for maximum ecological flow.

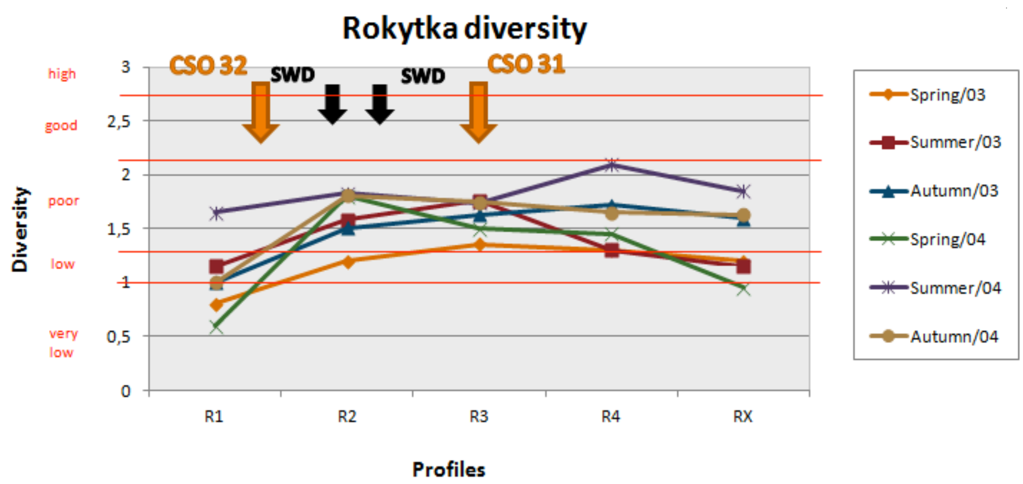
Continuous monitoring of flow showed that these determined ecological flows did not occur during the two years under study. In summer period the rate of flow had values below the minimum ecological flows. This caused lowering of water level, decreasing the number of suitable habitats and decreasing the concentration of dissolved oxygen, increasing water temperature and overall unacceptable living conditions for water macroinvertebrates. The consequence was a devastated creek with degraded macroinvertebrate community. Amount and frequency of overflows from CSOs often did not provide a sufficient time for macroinvertebrate to recover and so even encourage creek devastation [3]. A greater release of water from the Hostivar reservoir in the summer months would increase the water level and rate of flow and ensure the minimum ecological flow in the creek below the dam. A solution to decrease an extremely high rate of flow due to urban drainage overflows could be reduction of number of combine sewer overflows or reduction a peak discharges from overflows so the water body below wouldn't be affected by hydraulic stress.

ROKYTKA CREEK

Diversity

The variety of macroinvertebrate species in the Rokytka creek indicates poor to low diversity and in the case of the profile R1 very low diversity. The final diversity indexes vary among observed profiles (Graph **2**). Similar temporal trends in the diversity occur along the studied stream section, with exception of the site R4 during the summer 2003.

In contrast to the Botic creek, the observed CSOs on the Rokytka creek have positive effect on the biota. The sites located directly below the CSOs show a higher diversity index than the more distant profiles. The creek in this section has low velocity and straight direction without meandering. The river bed is covered by clay, silt and sand. The discharge from the CSOs therefore changes the rates of flow, removes fine material from the river bed and creates more diversified habitats of aquatic organisms. This confirms that the morphology and presence of suitable habitats is a driving factor in the biological quality of the stream.



Graph (2). Diversity index of the Rokytka creek, years 2003, 2004 [4].

Table 2. Range of ecological flows for Rokytka (Years 2003-2004) [4]

Creek	Q_{opt} / 03	Q_{min} / 03	Q_{max} / 03	Q_{opt} / 04	Q_{min} / 04	Q_{max} / 04
Rokytka - Spring	0.38 - 0.48	0.22 - 0.25	1.10 - 1.15	0.32 - 0.43	0.19 - 0.22	1.03 - 1.10
Rokytka - summer	0.45 - 0.54	0.25 - 0.28	1.15 - 1.20	0.42 - 0.52	0.22 - 0.25	1.03 - 1.15
Rokytka - Autumn	0.38 - 0.48	0.21 - 0.23	1.08 - 1.12	0.35 - 0.45	0.19 - 0.22	0.99 - 1.08

Ecological Flows

The creek is heavily affected by overflows from two CSOs and two SWDs and improvement of its ecological status is needed. The ecological flow values for each season of years 2003 and 2004 are summarized in Table **2**. Qopt/03 means again optimal flow for year 2003; Qmin/03 means minimum flow for year 2003 and so on.

The seasonal variation in the rate of flow has two main reasons: first, the differences in hydrological condition during the observation period, and second, the changes in representation of different species or different requirements on habitat quality during different life stages [4]. The ecological flow values for the Rokytka creek were determined as an average from values for 2003 and 2004, showed in Table **2**. The optimal ecological flow for Rokytka during spring is therefore 0.38 - 0.43 m^3/s, maximum 1.09 - 1.10 m^3/s and minimum 0.21 - 0.23 m^3/s. The range of values during summer is 0.45 - 0.52 m^3/s for optimal flow, 1.14 - 1.15 m^3/s for maximum flow and 0.24 - 0.26 m^3/s for minimum flow. The spectrum of autumn values includes the optimal flow range 0.38 - 0.45 m^3/s, maximum flow range 1.07 - 1.08 m^3/s and minimum flow range 0.21 - 0.22 m^3/s.

The flow data for the monitoring period revealed that the ecological range of flow values seldom occur. The extremely low summer rate of flow caused loss of aquatic habitat, decreasing concentration of dissolved oxygen and self-cleaning mechanisms. During periods with extremely high rate of flow the overflows from CSOs caused exceeding of maximum ecological flow. This results in morphological changes and losses of river bed material further downstream. In this case positive overall effects of the CSOs on the stream can be hypothesized, because the slowly moving straight urban creeks may become more interesting for aquatic organisms.

ZATISSKY CREEK

Diversity

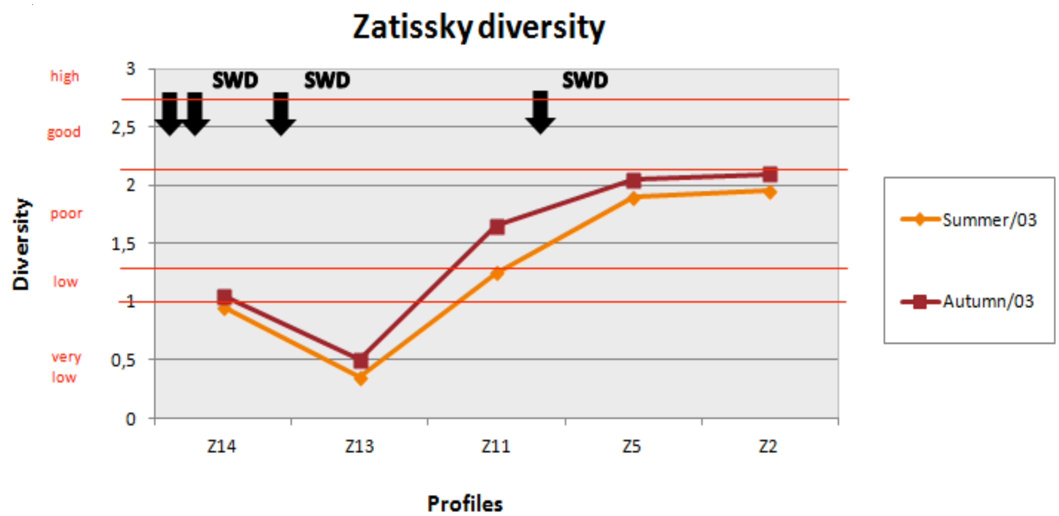
Only profiles which describe the influence of SWDs on this urban creek were considered for a comparison with the effects of CSOs. Graph **3** showed the diversity values during the observation period. The first section was represented by profile Z14 and showed a low diversity due to discharge of two inlets from SWDs. The following profile Z13 represents the second section where diversity is lower than in the profile Z14.

A trend of increasing diversity towards the third sector (see Fig. **3**) with higher diversity can be observed. In the upper part the diversity suffers from loads of fine sediment material and lack of suitable conditions for diversified habitats. This effect in the first two sectors was also caused by the slope of the creek (in the second sector between 2-5% compared to the third sector with 1.2%) and so SWD inlets in first two sectors completely changed the morphology of the stream channel. In the third sector the slope has changed and the effect of the discharge from SWD is not obvious.

Ecological Flow for Zatissky Creek

Monitoring of the Zatissky creek was performed during summer and autumn of 2003. Following values of ecological flow were computed (Table **3**).

Comparison of determined ecological flow and measured rate of flow in the profiles showed that the maximum ecological flow between two dams Zatisska and Pod Lysinami, sector 2, (see Fig. **3**) was substantially exceeded due to the inlets from SWDs. It increased the erosion and affected the structure of benthic organism and the morphology of the creek. This sector has a steep slope of 5%. But the minimum



Graph (3). Diversity of the Zatissky creek, year 2003 [4].

Table 3. Range of Ecological of Flows for Zatissky Creek (Year 2003) [4].

Creek	Q_{opt} / 03	Q_{min} / 03	Q_{max} / 03
Zatissky - Spring	-	-	-
Zatissky - summer	0.18 - 0.25	0.07 - 0.08	0.85 - 0.88
Zatissky - Autumn	0.18 - 0.25	0.09 - 0.10	0.83 - 0.85

Table 4. Comparison Between Identified Optimal Ecological Flows for Macroinvertebrate and Long-Term Average Flows [4]

Creek /Season	Spring	Summer	Autumn	Q_a - average
Botic (m^3/s)	0.32 - 0.38	0.42 - 0.45	0.38 - 0.48	0.350
Rokytka (m^3/s)	0.38 - 0.43	0.45 - 0.52	0.38 - 0.45	0.340
Zatissky (m^3/s)		0.18 - 0.25		0.002

Table 5. Comparison of Identified Minimum Ecological Flow with not Affected M-Day Flows [4].

Creek /Season	Spring	Summer	Autumn	QM - day
Botic (m^3/s)	0.20 - 0.21	0.19 - 0.21	0.22 - 0.23	Q_{210} - Q_{220}
Rokytka (m^3/s)	0.21 - 0.23	0.24 - 0.26	0.21 - 0,22	Q_{210} - Q_{220}
Zatissky (m^3/s)		0,07 - 0,09		-

Table 6. Comparison of not Affected N-Year-Flood Rate of Flow Corresponding with Maximum Ecological Flows [4].

Creek /Season	Spring	Summer	Autumn	QN - year
Botic (m^3/s)	0.93 - 0.95	0.95 - 0.98	0.95 - 0.98	Q_{1year}
Rokytka (m^3/s)	1.09 - 1.10	1.14 - 1.15	1.07 - 1.08	Q_{1year}
Zatissky (m^3/s)		0.83 - 0,85		Q_{5years}

ecological flow in the second sector was not reached. This sector was located between other two dams (Pod Lysinami and U vodotoku), sector 1 (see Fig. **3**), the rate of flow is very low and the creek is meandering. The inlets from SWDs in first sector supply a significant amount of sediment, which in warm summer days produce a strong smell and decreases the concentration of oxygen and the self cleaning ability of the creek.

Identified Optimal Ecological Flows and The Flow Conditions In The Creeks

A comparison was made of determined ecological flows with values given from Czech Hydrometeorological Institute, using Q_a - a long-term average rate of flow, M-day rates of flow (Q_{210}, Q_{220}) which presented a rate of flow running through creek M-days in year or bigger, and N-year-flood

Table 7. Recorded Number of Overflows and Volume of Overflowed Water [4]

Botic Creek	CSO83	CSO80 and CSO81
Number of overflows	18	34
Volume of overflowed water (m^3)	27300	7788
Peak discharge (m^3/s)	20141	352

rate of flow (Q_{1year}, Q_{5years}), presented flow that runs through creek at least N-year.

Optimal ecological flows in a case of Botic and Rokytka creek correspond with long-term average flow (Table **4**). In the case of Zatissky creek is obvious that long-term average flow is much lower than optimal ecological flow. During observation period were flows in all creeks higher than official average flows [4].

Minimum ecological flows in Botic and Rokytka creeks are not reached approximately one third of a year (Table **5**). In this case were compared minimum ecological flows with M-days rate of flow, exactly Q_{210} and Q_{220}, which presented flow that runs in creek 210 or rather 220 days in year. In both cases the values of M-days rate of flow were values not affected by urban drainage. For Zatissky creek a minimum ecological flow wasn't detected for all observation period.

From Table **6** is obvious that maximum ecological flows determined for Botic and Rokytka were equal the flows of 1-year-flood and for Zatissky creek the comparison showed that 5-year-flood compare its maximum ecological flow.

But M-day and N-year-flood rates of flow from Czech Hydrometeorological Institute are rates of flow not affected. From measurements performed during monitoring period is obvious that these rates of flow do not correspond with reality. For example in Botic creek were maximum ecological flows due to the CSOs exceeded more than nine times, but twice was the rate of flow higher than double value of determined maximum ecological flow. Table **7** show numbers of overflows during observation period, volume of water and peak recorded rate of flow during observation.

Destruction of invertebrates' population happened more than once a year and it's happened with every exceeding of maximum ecological flows. When the population is reduced fewer than 20% it loses regeneration ability and it may lead to problematic and time-consuming recolonization. Frequent exceeding of maximum ecological flows may lead to elimination of sensitive species and deformation of diversity of community.

The same problem was recorded at Rokytka creek.

A different problem occurred on Zatissky stream. The values given as M-day and N-year rates of flow were measure in 70's of last century and they did not match with reality because of increase of impervious surface in watershed. During measurement a data was recorded that was ten times higher than values given by Czech Hydrometeorological Institute. This could lead to wrong conclusion.

CONCLUSION

The performed calculations of minimum, optimal and maximum ecological flow for macroinvertebrate community on three urban creeks in the Prague metropolitan area have shown that urban drainage systems significantly affect the ecological status of the urban streams. CSOs and SWDs affect the hydrological conditions of the streams and cause a smaller diversity of the macroinvertebrate communities. The studied creeks often suffer from hydraulic stress caused by urban drainage. The computed minimum ecological flow was not reached during any summer on any of the three creeks. The low water rate of flow caused defragmentation of the microhabitats, increase of water temperature, and decrease of dissolved oxygen concentration and self-cleaning capacity of the creeks. In contrast, rain events have elevated the rate of flow beyond the maximum acceptable ecological flow and caused a removal of sediment and sediment bind biota from their original habitats. The comparison of the obtained results has shown that with this frequency of the overflows in the Botic creek, the biota does not have sufficient time for recovery. Rokytka creek showed higher diversity due to the overflows, especially in profiles with sand, silt and clay. Overflows caused changes in river bed material and they provided more habitats for macroinvertebrates. In case of Rokytka creek determined ecological flows seldom occur, but extremely low summer rates of flow caused decreasing of concentration of dissolved oxygen and losses of habitats. Also due to the CSOs were exceeded maximum ecological flows which lead to morphological changes. It is possible to say that Rokytka creek showed significant negative affections that had CSOs on urban creek and in a special occasions some of positive affections. Zatissky creek was affected only by SWDs, which caused big morphological changes in first two sectors of a creek, for example erosion problem due to the exceeded maximum ecological flow in second sector. But also there was not reached a minimum ecological flow. Due to the morphological changes such as meandering and erosion was decreased a slope in a first sector, material from SWDs was settled. Observation on Zatissky creek was held only for one year but still in possible to detect negative affections from SWDs. Volume of transported material from SWDs negatively affect creeks morphology and chemistry. This can be solved by sedimentation dams below SWD inlets.

The study has shown that calculation of the optimal ecological flow for aquatic biota is one of the most important requirements to identify crucial stressors affecting urban streams and to propose restoration measures in both the streams and catchments. A proper management of discharge from urban drainage to recipients would also improve the ecological status of streams and support the revitalization of damaged stream channels.

This paper also showed that optimal ecological flows determined for individual years differ due to seasonal conditions and preferences of aquatic macroinvertebrate during their life stages. The study also showed that the impact of

CSOs on the creek morphology is not always negative; for example, the CSOs in modified straight stream channels with a low flow may lead to a bigger diversification of the micro-habitats and bottom sediments.

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