České vysoké učení technické v Praze, Fakulta stavební

Czech Technical University in Prague, Faculty of Civil Engineering

Doc. RNDr. Dana Komínková, Ph.D.

Městské odvodnění a urbanizované toky

Urban Drainage and Water Recipients

Summary
Progressing urbanization and migration of population from rural to urban areas bring new challenges to the management of urban waters, particularly in preservation or restoration of aquatic habitats and in improving of the environmental sustainability of our cities. Urban environment does not only affect the water quality by a continuously growing input of anthropogenic substances, but mainly changes the hydrological cycle via increasing amount of impervious surfaces in catchments.

Urban drainage is on one hand an essential part of urban sanitation, but at the same time one of the main causes of stream deterioration. The recently adopted term “urban stream syndrome” summarizes the degradation of streams and aquatic biota in urban areas, characterized by flashier hydrograph, changes to channel stability and morphology, and deterioration of water and sediment quality.

The recent status of stream degradation in Prague, using an example of two creeks affected by different type of urban drainage - combined sewer and storm water drain, is presented. The long term monitoring and assessment of the two creeks, Botič (combined sewer) and Zátišský creek (storm water drains), has shown that the urban drainage affects all parts of the aquatic environment. The channel morphology is altered by the stormwater which discharges directly to the creek and causes a hydraulic stress accompanied by removal of the sediment, outwashing of sensitive species and changes in the behavior of priority substances, mainly toxic metals. The type of urban drainage plays an important role in increasing/decreasing bioavailability. As a consequence of the degradation, the creeks do not achieve good chemical and ecological status, and are classified as heavily affected waterways.

Possible approaches for restoration of the creeks include decrease of effective imperviousness, increase of retention and later use of the stormwater. The restoration of an urban creek is not possible without good understanding and communication between engineers, architects, city planners and natural scientists.

Souhrn

Pokračující urbanizace a migrace obyvatelstva do měst s sebou přináší řadu problémů pro vodní hospodářství. Zejména se to týká ochrany a revitalizace vodních habitatů a zlepšení environmentální udržitelnosti měst. Vliv měst na vodní toky se neomezuje pouze na změny kvality v důsledku rostoucího množství antropogenních látek vstupujících do vodního prostředí, ale zejména způsobuje změny hydrologického cyklu jako důsledek nárůstu podílu nepropustných ploch v povodí.

Městské odvodnění je základem ochrany obyvatelstva před zdravotními riziky, ale je také jednou z hlavních příčin degradace vodních toků. V posledních několika letech se rozšířil pojem syndrom urbanizovaných toků, který identifikuje degradaci městských toků. Tato je charakterizována změnami hydrogramu s výskytem bleskových povodní, snížením stability koryta a zvýšenou erozí, zhoršením kvality vody a sedimentu. Uvedené změny prostředí vedou k narušení vodní bioty.

Na příkladu dvou drobných toků ovlivněných různými typy městského odvodnění, jednotnou a oddílnou dešťovou kanalizací, je prezentována současný stav degradace drobných toků v Praze. Dlouhodobý monitoring a hodnocení stavu Botiče (jednotná) a Zátišského potoka (oddílná dešťová kanalizace) ukazují, že městské odvodnění ovlivňuje všechny složky vodního prostředí. Zaústění dešťových vod do toku způsobuje nejen změny v morfologii toku, ale výrazně přispívá k zvýšenému pohybu sedimentu a odplavení citlivých organismů. Důležitým zjištěním je také, že typ městského odvodnění ovlivňuje chování prioritních polutantů, zejména toxických kovů, a mění jejich biologickou dostupnost. Sledované toky nedosahují dobrého chemického a ekologického stavu a je možné je označit jako silně pozměněné útvary.

Možné řešení stávající situace je revitalizace vodních toků, která bude v první řadě zaměřena na snížení množství dešťových vod vstupujících přímo do toku (snížení efektivní nepropustnosti, zadržení vody v povodí a pozdější využití) a následné revitalizaci koryta.

Revitalizace městských toků a následný návrh udržitelných nápravných opatření nejsou možné bez nalezení společného jazyka mezi inženýry, architekty, urbanisty a přírodovědci, nutného pro pochopení procesů, které se v povodí odehrávají.

Klíčová slova: městské odvodnění, jednotná kanalizace, oddílná dešťová kanalizace, odlehčovací komora, vodní tok, hydraulický stres, ekologický stav, nápravná opatření, syndrom urbanizovaných toků

Keywords: urban drainage, combined sewer, storm water drains, combined sewer overflow, stream, hydraulic stress, ecological status, mitigation measures, urban stream syndrome

Motto:
Sestřičko vodo, děkuji, že tak dlouho a trpělivě smýváš všechnu špínu světa.

Modlitba sv. Františka z Assisi

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1 INTRODUCTION

Urbanization is a process of physical growth of urban areas and movement of human population from rural to urban areas. While at the beginning of 20th century only 10% of the world´s population lived in urban centres, in 2006 it was already 50% of the human population [9]. In developed countries the proportion is even higher, for example in Australia already 90% of population live in cities [33]. In the Czech Republic already 74.6% of inhabitants live in cities. As this proportion increases with time, local and global environmental impacts of urban areas also increase. The extent of urbanization impacts on aquatic ecosystems is typically growing faster than the rate of urban population growth, because advances in communication and the increased desire for personal green space often promote decentralization and urban sprawl [32]. These landscape changes manifest themselves by conversion of forest and rural land to residential, municipal and commercial uses as the human population and its demand for land increase [13][51][52], particularly near water bodies. Urbanization as the final phase of transformation in land use causes a deep impact on natural connection between soil and aquatic environment [38].

Urbanization affects different parts of the aquatic system. The most serious problems caused by urbanization are changes of the hydrological cycle, in particular the surface runoff characteristics, leading to changes of hydromorphological and hydrodynamic conditions of the stream The other significant effect is on chemical state of the urban recipient, leading to changes of the biota [11][38].

Proper understanding and management of the urban drainage system is therefore crucial for ensuring sanitary and environmental safety for urban populations.

2 URBAN DRAINAGE

The current definition of the urban drainage system purpose is to safely and quickly drain all types of waste water (e.g. from households, industry) as well as surface runoff from impervious surfaces and infiltrated water from urban areas into waste water treatment plants (WWTP) [28]. The goal of the urban drainage is to provide sanitary and ecological safety for human population living in urban areas.

The urban drainage system consists of sewer system, waste water treatment plant and the receiving water body, usually river or creek.

The goal of this work is to demonstrate the interactions urban drainage - recipients within the entire urban drainage system. Therefore only those parts of urban drainage are mentioned, which are in direct contact with the recipient.

The simplest way to categorize sewer system is by the type of drained waste water. While the combined sewerage (CS) is the oldest type of sewer system draining both waste water and the surface runoff incl. infiltrated water to the WWTP, the storm water drains (SWD) operate only during rain events and drain the surface runoff only. The CS operates continuously; during dry period all waste water goes to the WWTP, but during rain events a part of the diluted waste waters overflows to the recipient. Combined sewer overflows (CSO) satisfactorily treat the technical and economical limitation of sewerage and WWTP operation; however, they are important source of pollution and cause a hydraulic stress for the aquatic biota.

The definition and operation of urban drainage cause the following problems for protection of the receiving water bodies:

- Quick drainage of surface runoff from impervious surfaces causes increase of natural discharge of small creeks.
- The rapidly drained surface runoff cannot recharge the ground water.
- Pollution of recipients during rain events and snow melt increases.
- The diluted waste water diminishes the efficiency of WWTP.
- Biological diversity of the aquatic community decreases.

There is an urgent need for a new definition of urban drainage which would include not only protection of human population, but also protection of the environment from anthropogenic activities.

The complete understanding of the urban drainage effects on recipients is crucial for sustainable protection and restoration of aquatic systems.

3 URBAN STREAMS

Urban streams are highly vulnerable to impacts associated with land use changes resulting from the increasing urbanization. Streams play an important role in the urban areas as 1) carriers of water and suspended solids; 2) habitats for diverse and productive biota, and 3) social and cultural elements for human inhabitants living in the catchment [48].The impact of anthropogenic activities on streams has substantially increased during the recent years, and the streams are losing their natural character rapidly. In Europe, only a few recipients are not directly or indirectly affected by urban areas.

The increasing number of affected streams has attracted the research communities, motivating them to develop new concepts and technical terms expressing the problem of urban streams. The term "urban stream syndrome" describes the consistently observed degradation of streams draining urban land [24][33][37][48].

The symptoms of the urban stream syndrome include a flashier hydrograph, elevated concentration of nutrients and contaminants, altered channel morphology and reduced biodiversity [24][48]. These effects are often accompanied by other symptoms which are not observed in all urban areas, such as reduction of baseflow and increase of suspended solids concentration. Although most of the symptoms show consistency in their occurrence in urban areas all around the globe, their degree to which they change the aquatic ecosystems is highly variable and depends on local conditions. The main symptoms are summarized in Table 1.

The mechanisms driving the syndrome are integrated and variable, but most of the impacts result from a few major large scale sources, primarily from urban storm water runoff delivered to stream by hydraulically efficient drainage system [48]. Other stressors include combined sewer overflows, waste water treatment plant effluent, legacy pollutants (long-lived pollutants from earlier land use), and illegal discharges of waste water. Most of the research on urban drainage impact has focused on correlations between stream chemical and biological metrics and various topographical or hydraulic parameters, such as total catchment imperviousness, distance between stream reach and urban land and hydraulic efficiency of the sewer system.

Tab. 1 Symptoms associated with the urban stream syndrome (modified from [48][24]) (* correlation with level of urbanization was not clearly proved)

Feature	Symptom
Hydrology	Increasing frequency of overland flow
	Increasing frequency of erosive flow
	Increasing magnitude of high flow
	Decreasing lag time to peak flow
	Increasing rise and fall of storm hydrograph
	Changes of baseflow magnitude *
Water and sediment chemistry	Increasing concentration of nutrients (P, N)
	Increasing concentration of toxic substances
	Increasing temperature
	Increasing concentration of suspended matter *
	Decrease of organic matter retention
Channel morphology	Increasing channel width
	Increasing pool depth
	Decreasing stability of the channel
	Increasing scour
	Disturbance of the river continuity
	Changes in sedimentation processes *
	Enrockment of banks
Fish	Decrease of sensitive species
	Increase of tolerant species*
	Changes of abundance*
	Changes of biomass*
Invertebrates	Increase number of tolerant species
	Decrease number of sensitive species
	Decrease number of predators*
Algae	Increase number of eutrophic diatoms
	Decrease number of oligotrophic diatoms
	Changes of biomass*
	Presence of toxic algae
Ecosystem processes	Decrease in nutrition uptake
	Leaf breakdown
	Net ecosystem metabolism*
	Nutrition retention
	P:R ratio

The focus will be primarily on small streams, because they are the most abundant of receiving waters and because, with the small catchments, they are very sensitive to land use changes. The response of small streams to land use changes can serve as a warning signal of the potential deterioration to downstream waters. Equally, the protection of small stream ecosystems will assist the protection of large receiving waters downstream [50].

3.1 Hydromorphological changes

Increasing amount of impervious surfaces and decreasing area of natural vegetation cover belong to the most pronounced characteristics of urbanization. These changes significantly alter the hydrological conditions in the catchment and the behaviour of streams. The high amount of impervious surfaces causes a substantial increase of surface runoff components, along with a decrease of groundwater recharge and base flow.

The amount of water entering the recipient during rain events is significantly larger and causes increase of flow, the streams tending to be more “flashy”. The rising and falling limbs of the hydrograph are steeper and the maximal flow often exceeds the natural maximal flow from pre-urbanized period. Storm waters quickly drained during rain events by conventional sewer do not reach the aquifers and therefore the base flow is lower than the natural base flow (Fig.1).

The increasing volume and frequency of high flow on one hand requires stronger flood protection and mitigation of negative flood impact on the ecological integrity of the receiving streams and their inundation zones.

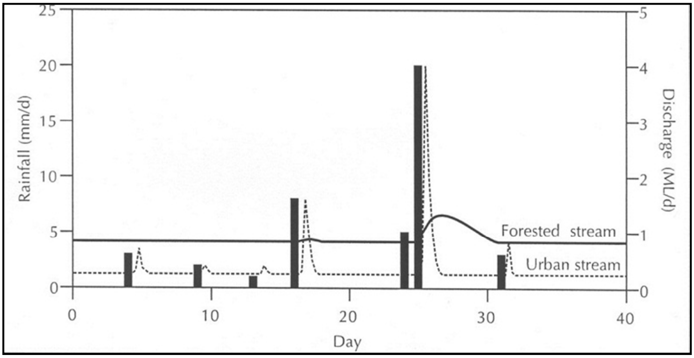

Fig.1. Schematic diagram showing flow response to rainfall (bars) in two hypothetical streams with a catchment of 1 km^2; one draining a forest catchment (solid line) and one draining an urbanized catchment with conventional stormwater drainage systems (dashed line) [50].

The construction of sewer systems also results in alternation of the catchment area and the stream length. These changes are manifested directly as a shift in the surface runoff volume, and indirectly in shortening the critical duration of rain and increase the intensity of the design rain. The urbanization causes higher flood frequency.

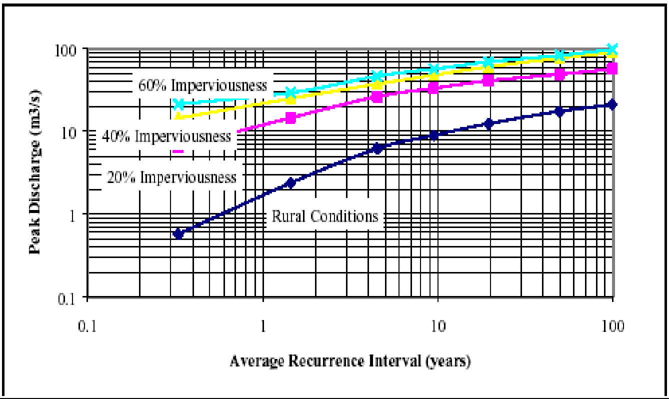

Fig. 2 Flood Frequency Curves for varying degree of urbanization [18]

While in natural catchments the flood periodicity is 1.2-2.4 years, in urban catchment the flood may occur several times a year [38] (Fig. 2). Increase of the recurrence interval of flood flows causes higher erosion and hence enlargements of stream channels.

The current flooding zone may therefore not correspond with flooding zones reported in the history for the same recurrence interval.

Important impact of urbanization on streams is also a disturbance of the movement of organisms through construction of artificial reservoirs and steps together with channel straightening. A consequence, large segments of the streams are becoming impassable for aquatic organisms. The impact on aquatic biota due to enlargement of stream channels is particularly pronounced during drought or decrease of the stream water level. On the contrary, an enhancement of maximal flow causes decrease of channel stability and increase of erosion risk. This means alternation of stream morphology, loss of the bank environment, lower water quality caused by high amount of suspended solids and siltation of the channel. The morphological change of the streams inhibits natural succession of aquatic biota and destroys natural habitats [23][23][24].

3.2 Chemical and physical changes

The quality of aquatic environment in urban areas is affected by waste water entering the stream from the system of urban drainage (combine sewer overflows, storm water drains, WWTP effluents, illegal discharges). The waste water discharges alter water and sediment quality and cause changes to the chemical status of the recipient.

While during dry weather the receiving waters are affected mostly by the wastewater treatment plant (WWTP) effluents or other continuous sources and the impact on receiving waters depends on the treatment efficiency of WWTP and the level of dilution, the quality of the aquatic environment during wet weather is affected not only by WWTP, but mostly by direct surface runoff and the SWDs and CSOs flows. The rainwater and surface runoff contain insoluble substances, organic micropollutants, and toxic metals from traffic and local heating systems as well as from commercial and industrial sources [14]. These substances accumulate during dry-weather periods on the catchment surface and are washed off during the rain. The water entering the recipients from CSO outfalls is a mixture of rainwater, municipal sewage, industrial wastewater and sediment (sewer sludge) accumulated in the sewer system during dry periods. The winter surface runoff can also contain high amounts of salts and insoluble substances [31].

The water quality in receiving waters deteriorates during rain events, leading to negative impacts on aquatic biota. One of the basic chemical parameters, pH, is very often impacted during rain events. While in water bodies impacted by CSOs pH can increase during rain events due to higher concentrations of ammonia originating from the sewer system and developing from ammonium ions, a decrease of pH is often observed in receiving waters affected by SWDs. The decrease of pH is usually observed in small creeks where the discharge of SWDs into the creek may exceed the creek flow rate upstream of the discharge point [20]. The decrease of pH (below 6) affects the mobility of pollutants, especially toxic metals, which become more mobile and bioavailable to aquatic organisms [6][22] [34].

The pollution by biodegradable organic substances often causes a decrease of the dissolved oxygen and changes in redox conditions of the aquatic environment. Changes in the redox potential may cause remobilization of metals and other pollutants from sediment and hence increase their bioavailability [39]. Insufficient concentration of dissolved oxygen increases negative effects of toxic substances on aquatic biota. Beside pH and redox potential, the partitioning behaviour and spatial distribution of pollutants in the aquatic environment is regulated by hydrodynamics, biogeochemical processes and other environmental conditions, including salinity, temperature and particle size distribution of sediments [7]. Changes in sediment chemistry due to bottom disturbance can result in contaminant remobilization. Subsequently, exposure to different chemical conditions could result in desorption and transformation of contaminants into more bioavailable or toxic chemical forms [12]. The fate of toxic metals and other priority pollutants in the urban creeks environment can then lead to higher uptake of pollutants by aquatic biota. Concentrations of priority pollutants (mainly toxic

metals, PAH, PCB, etc.) in sediments usually exceed those in overlying water by three to five orders of magnitude [3][25][34].
Higher concentrations of suspended matter enlarge the risk related to presence of toxic substances adsorbed on surface of the solid particles (e.g. toxic metals).
Runoff from roads and agriculture area is often enriched by nitrates and nitrates (toxic for fish), sulphates, which are affecting the calcium carbonate equilibrium and consequently they are affecting hydrochemical stability and aggressivity of water.
Surface runoff from roads may increase concentration of carcinogenic polycyclic aromatic hydrocarbons (PAH), known for a high stability and ability to accumulate in sediments, and nonpolar hydrocarbons substances originating from petrol, accumulating in organisms and sediments and being highly toxic to zooplankton.
The pollution load is closely related to the rain characteristics. Sobota [41] mentioned that 90% of the COD input is associated with the beginning of intensive rain (15-20% of rain duration) – first flush. In the case of less intensive rains, the increase of pollution concentration is delayed and less rapid.
Another physical factor negatively affecting water recipient is increasing temperature caused by warmer surface runoff from impervious surfaces, missing bank vegetation and also proximity of buildings reflecting light. The heat may change the temperature regime of the stream, because the stream temperature increases and the periods of natural cold become shorter.

3.3 Changes of the biological component of the aquatic environment

The stream ecosystem has to be considered as a closed complex, where each part has its own function. The aquatic biota is composed by different types of organisms, producers (phytoplankton, macrophytes), consumers (zooplankton, invertebrates, fish) and decomposers (bacteria, fungi). Loss or restriction of one of the group will cause collapse of the whole ecosystem.
The impact of water on biota includes both the water quality and quantity.

The population of aquatic organisms is closely correlated with the water quality. Water quality directly affects the abundance (population density), reproduction, and survival, ratio of sex, age structure and, in particular, the long term biodiversity. The aquatic organisms are used as indicator/ bioindicator, of water quality. The most common group of bioindication organisms are fish, macroinvertebrates and diatoms. Especially diatoms and macroinvertebrates are very good indicators of urban drainage impact [1][46][48].

The impact of water quantity in urban areas is affected by the level of urbanization and amount of impervious surfaces. In the past, the question of water quantity was mostly focused on minimal flow (Q_{355}), but in urban catchments the situation is more complicated. On one hand, the minimal flow is often not maintained, especially during dry months. On the other hand, the surface runoff during rain events is drained to the stream and the maximal acceptable flow is frequently exceeded. Exceeding of the maximal flow causes washout of organisms not resisting against such a high flow. In this case the whole food chain is dislocated, and the recolonization of the community requires several weeks or months. In case of frequent summer rains, the disturbance repeats before the biota can recover, which disturbs the community seriously.

The state of the biota is also a crucial indicator of the ecological status of water bodies according to the EU Water Framework Directive [10]. Hence, it is necessary to sustain diversified biotic communities in water bodies and fulfil the requirements of the Directive on achieving a good ecological status of all water bodies within the EU by 2015 [10].

4 CASE STUDY

A long term study of urban drainage impact on receiving water is presented on an example of two creeks in Prague, Botič and Zátišský creek.

4.1 Study area

The studied creeks (Botič, Zatišský Creeks) are located in Prague (the capital of the Czech Republic) and both are right-hand tributaries of the Vltava River (Fig. 3). The Botič, the largest tributary of the Vltava River in Prague, is mainly supplied by CSOs and SWDs, while Zatišský Creek is affected by SWDs only. Table 2 provides more detailed information about the creeks.

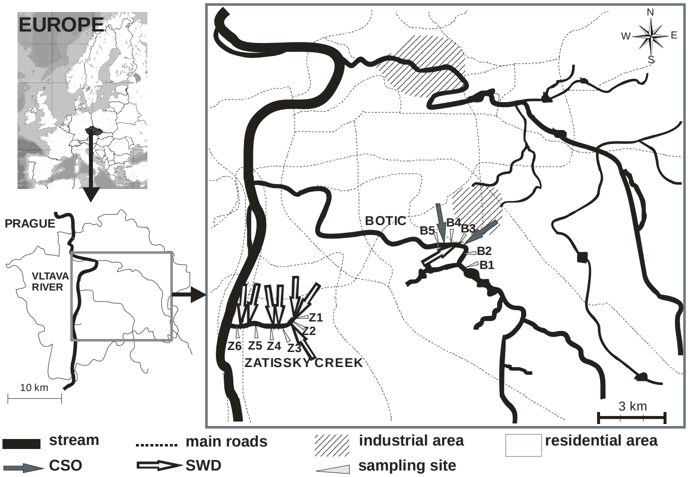

Fig.3: The map of creeks studied [26]

The upstream part of the Botič catchment is characterized by agricultural land use, with suburban settlements; the urbanized downstream parts are affected by urban effluents, including wastewater from printing shops and electrical, chemical and machine-building industries entering the creeks through the CSOs. The creek is also affected by the large Hostivař reservoir. Zatišský Creek runs through a residential development and a partially forested area, and there are three stormwater management ponds on the creek.

Tab. 2 Basic characteristics of the creeks studied (* in parenthesis: number of outfalls in the study section)

	Botič (B)	**Zátišský cr. (Z)**
Length [km]	34.5	3.1
Catchment area [km^2]	135	3.02
Average discharge [m^{3}s^{-1}]	0.4	0.025
Type of drainage*	CSO (2), SWD	SWD (7)
Length of the study section [km]	2	2.9
Annual overflow volume [m^3.year^{-1}]	47 500	87 700

4.2 Methods

The assessment of the urban drainage impact on streams was based on a long term hydromorphological, chemical and biological monitoring. The Botič has been monitored since 2000, and the Zatišský creek since 2002.

4.2.1 Hydromorphological monitoring

The morphological status of both creeks was assessed by the methodology presented in [21][23].
The hydrological- biological assessment was based on long term monitoring of the flow and identification of the optimal ecological flow for macroinvertebrates. The optimal and maximal acceptable flows were identified by use of the IFIM methodology and the simulation tool PHABSIM [2][5].

4.2.2 Chemical monitoring and assessment of the chemical status

The chemical monitoring was conducted at different levels. Basic parameters of water quality (pH, conductivity, $N\text{-}NO_3$, $N\text{-}NO_2$, $N\text{-}NH_4$, $P\text{-}PO_4$, COD, Cl^- etc.) and concentration of priority substance (toxic metals, PAU) in water and sediment were measured [23][27][35]. Toxic metals were also identified in the biomass of macroinvertebrates [22][25].

4.2.3 Biological monitoring

The biological monitoring was based on the assessment of the macroinvertebrate community [24][35][43][44]. The main metrics used for evaluation were diversity and abundance.

4.3 Results

4.3.1 Hydromorophological assessment

The morphological assessment of the creeks is summarized in Table 3.

Tab 3. Percentage of the creek length maintaining the morphological status of the following five categories (1.cl- natural; 2.slightly modified; 3.obviously modified; 4.significantly modified, 5. Artificial character) (Contin.- objects which affect the river continuum- R- reservoir, W-wear) [24].

Creek	1.class	2.class	3.class	4.class	5.class	Contin.
	%					
Botič	24	50	16	8	0	R, W
Zatišs.	5	15	40	30	10	R

The assessment indicates that both the streams are affected by human induced erosion due to operation of the sewer system. The disturbed morphology of the streams is one of the factors causing low biological diversity [24].

Identification of optimal and maximal acceptable flow (tab 4) has demonstrated that aquatic organisms are exposed to hydraulic stress during rain events caused by the storm water discharge to creeks. On the contrary, the flow during drought is below the minimal acceptable value and the organisms are stressed by insufficient amount of water [5][23].

Tab. 4 Ecologically acceptable range of flow ($m^3.s^{-1}$) [5] [23]

Season	Minimal	Optimal	Maximal
	($m^3.s^{-1}$)		
Botič			
Spring	0.21-0.23	0.38-0.43	1.09-1.1
Summer	0.24-0.26	0.45-0.52	1.14-1.15
Fall	0.21-0.22	0.38-0.45	1.07-1.08
Zátišský creek			
Spring	It was impossible to identified the range of flow, due to a small number of collected organisms		
Summer	0.007-0.008	0.018-0.025	0.085-0.088
Fall	0.009-0.01	0.018-0.025	0.083-0.085

Fig. 4 shows the high frequency of occurrence of hydrological situations causing stress for aquatic biota. With respect to time needed for restoration of the biotic community (25 -35 day) [30][15], the disturbance of the biota occurs too often and the community does not have sufficient time to recover. Each rain episode therefore increased the degree of the biota degradation.

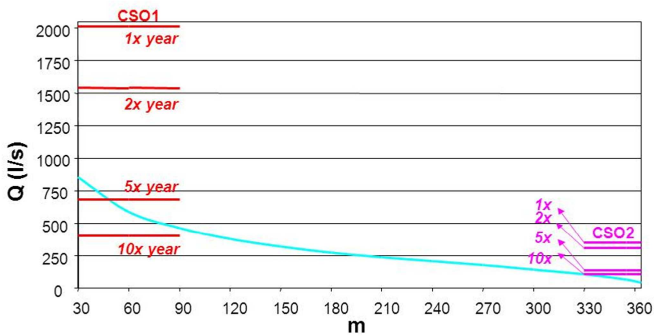

Fig. 4 Unaffected discharge frequency curve of Botič creek compared to top discharges caused by CSOs [27]

The altered flow of both streams plays important role in degradation of the biotic community.

4.3.2 Chemical assessment

The assessment of the chemical status of the creeks was based on water and sediment quality evaluation. The water quality was evaluated by the environmental quality standards identified in the Czech legislation [36]. The evaluation of the sediment quality is less straightforward, because the Czech legislation does not provide environmental quality standards (EQS) for all priority substance monitored on the studied creeks. In addition, the identified EQS are considered for different sediment fraction than the monitored one (monitored fraction was 630µm, while the legislation works with 20µm for toxic metals and 2mm for PAH and other organic substance). Therefore the evaluation of the sediment quality was based mainly on international standards, such as US EPA benchmarkers identifying threshold effect concentrations (TEC) and probable effect concentrations (PEC) [46].

The creek affected by CSOs (Botič Creek) suffered mostly by deterioration of COD (chemical oxygen demand - dichromate reflux method, EQS–26 $mg.l^{-1}$), BOD5 (biological oxygen demand; 3.8 $mg.l^{-1}$). During acute events, when the combined sewer was overflowing, deterioration of suspended solids (20 $mg.l^{-1}$), $N\text{-}NO_3$ (5.4 $mg.l^{-1}$), $N\text{-}NH_4$ (0.23 $mg.l^{-1}$) was observed. The water quality of Zatišský Creek satisfies the ambient water quality limits during most of the time; only in some cases TOC (10 $mg.l^{-1}$), TP (0.15 $mg.l^{-1}$) and total suspended solids exceeded the ambient water quality [26].

Concentrations of toxic metals and PAH in water in general meet the requirements of the ambient water quality.

The content of toxic metals in sediments was identified by use of two methods: digestion by HNO_3 to identify the pseudo total (available) fraction of the metals, which can be up-taken by sediment-dwelling organisms (macroinvertebrates), and the sequential extraction [34] to identify content of metals in different geochemical fractions. The measured available concentrations are summarized in Table 5. The maximum and mean concentrations are listed together with the cumulative criterion unit (CCU – factor indicating cumulative effect of all metals) [8][23]. The concentrations of metals vary significantly among the creeks affected by different types of urban drainage systems. Creek receiving CSOs (Botič Creek) exhibits high concentrations of three most ubiquitous urban metals copper, zinc and lead.

Tab 5: Concentration of selected toxic metals in sediment ($mg.kg^{-1}$). The shadow values exceed the TEC benchmarker and identified concentrations which may cause negative effect on biota.

Site	Cu		Zn		Pb	
	Max	Mean	Max	Mean	Max	Mean
B1	14	12	41	36	10.7	9.9
B2	35	17	143	62	42.3	15.1
B3	215	96	546	169	108.8	51.6
B4	121	59	302	129	64.6	38.1
B5	88	49	129	87	40.5	28.3
Z1	25	22	130	116	51.3	31.6
Z2	19	11	121	60	11.4	7.7
Z3	16	8	112	47	15.3	8.6
Z4	7	5	59	45	7.9	6.5
Z5	8	6	54	44	9.8	7.4
Z6	13	9	55	46	25.9	11.2
TEC	28		159		34.2	

Site	Ni		Cr		Cd		CCU	
	Max	Mean	Max	Mean	Max	Mean	Max	Mean
B1	13.4	11.6	16	16	0.070	0.061	1.8	1.6
B2	16.5	8.2	20	10	0.213	0.164	4.5	2.1
B3	36.3	16.6	82	42	0.579	0.309	17.6	7.7
B4	25.0	11.6	56	24	0.460	0.276	10.5	5.2
B5	25.6	11.1	37	18	0.110	0.110	6.6	3.9
Z1	20.9	13.5	20	16			4.1	3.1
Z2	30.4	12.3	23	12			3.0	1.5
Z3	44.2	15.2	49	17	0.051	0.051	3.8	1.6
Z4	21.1	12.9	13	9	0.013	0.013	1.6	1.2
Z5	14.3	9.9	16	10	0.078	0.077	1.7	1.3
Z6	16.8	10.5	15	9	0.101	0.101	2.4	1.5
TEC	39.6		56		0.592			

In case of these elements, maximum and mean concentration values also exceed the toxicological benchmark TEC, identifying a possible negative effect on biota. In case of the creek affected by SWD, the metals in sediment were usually detected at lower levels, and therefore they represent low risk for macroinvertebrates with respect to the assessment by TEC [26].

The assessment of sediment contamination on basis of the cumulative criterion unit (CCU) and its impact on aquatic biota, especially macroinvertebrates, shows that in the case of Botič Creek the biota is exposed to a high risk due to concentrations of metals in sediments. The intermediate level of risk was also indicated at some sites on Zatišský Creek.

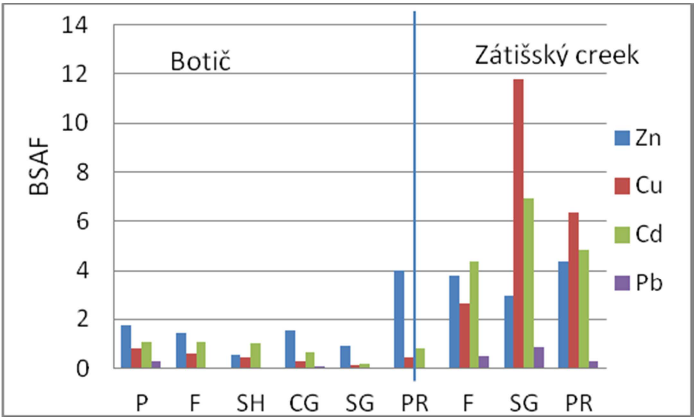

Fig. 5 Biota sediment accumulation factor (BSAF) for feeding groups (BSAF>1 indicates accumulation to concentration higher than sediment concentration) (P-producer, F-filterer, SH-shredder, CG-collector-gatherer, SG-Scaper-grazer, PR-benthic predator, FH-fish) (modified from [22]).

The results of toxic metals bioassays are presented in Figure 5. They are depicted by feeding groups to indicate the occurrence of metals in the food chain. Due to the extent of modification of the urban water bodies, not all feeding groups are present in both streams studied.

There are significant differences between bioaccumulation of metals by organisms in creeks impacted by SWDs and CSOs. Organisms in creeks affected by CSOs accumulate toxic metals to lower levels than organisms (of the same size and species) in creeks impacted by SWD, even though the CSO creek is more polluted. The biological availability of metals in creek affected by CSO is lower than in creek impacted by SWD. The bioavailability of metals is dependent on environmental conditions and their modification [25] [26].

The chemical status of the creeks, in particular the occurrence of priority pollutants in sediments, may result in lower biological diversity of the streams.

4.3.3 Biological assessment

The biological assessment was based on monitoring of the macroinvertebrate community. It has shown that the community on Botič has an extremely low diversity and that the community is characterized by high abundance of tolerant species and missing sensitive organisms [23] [42].
The Zatišský creek has a worse state of the macroinvertebrate community, with extremely low biodiversity and abundance [23].

4.4 Summary

The urban drainage causes the following effects on the monitored creeks (Botič and Zatišský creek):

- Morphological degradation of the channel.
- Hydraulic stress for the aquatic biota.
- Chemical deterioration of the ecosystem, mainly by introduction of priority substances with high ability to accumulate in the sediment and biota.
- Damage to the biotic community.

The unsatisfactory state of the benthic community is caused not only by combination of all these factors, but also by presence of reservoir, which causes alternation of stream continuum [42].
The Botič and Zatišský Creek are typical examples of streams affected by the urban stream syndrome.
According to the requirement of the EU Water Framework Directive [10], the creeks do achieve neither a good chemical status,

nor a good ecological status. Both of the creeks can be characterized as heavily affected by urban drainage.

5 URBAN STREAM SYNDROM AND NEW TRENDS IN WATER MANAGEMENT

Urban streams have the potential to provide precious natural resources to humans who live near them [33]. In many cities of the world this potential is far from fully realized, because most urban developments have involved transforming streams into drains or sewers. The primary goal of the urban waterway management for most of the 20th century was protection of humans from floods and diseases. Although this goal must remain the first priority, traditional approaches to waterway management for public health and safety have been at the expenses of the other goals, such as public amenity and ecosystem health [48]. New approaches in urban design and waterway management show great potential for achieving all public safety and amenity goals, together with goals of improved ecological conditions in streams of many urban areas [29].

Restoration of waterways has become an important tool of the water management during the last decade, and it remains crucial for improvement of ecological conditions of streams. Restoration of waterways is not a new tool in water management; the approach to restoration and the understanding of the waterway´s functioning with positive effects on the restoration are however innovative elements.

The first step of restoration is a clear identification of the target state of the stream/river which should be achieved, and the second step includes the identification of control indicators. Currently, these indicators are mostly parameters indicating the quality of the aquatic biota, e.g. biodiversity and abundance. In the future, the parameters should indicate the function of the aquatic ecosystem, such as gross primary production, respiration of the community, etc. [17].

The restoration measures leading to the improvement of the ecological status are short term and long term. The group of short term measures includes embankment, planting of bank vegetation, pollution source control, fish pass, and construction of remedial measures directly in the stream channel, but also the end-of-pipe strategy measures such as retention and detention reservoirs. The short term measures provide solution for acute problems typical for urban streams channels, but they do not result in increasing biological diversity of the aquatic community and usually they are not sustainable in the long term perspective. These measures do not respect the catchments processes, and are also highly demanding on continuous maintenance and may become financially unacceptable. The long term measures do respect catchment processes at their real scale and therefore are self-maintained. The long term measures include changes in land use, creation of buffer zones along the streams, restoration of hydrological conditions (infiltration of stormwater, decrease of effective imperviousness), rehabilitation of bank vegetation and support of its natural zonation and restoration of the connection between flood plain and the stream channel [4].

Number of papers [16][17][19][33][40] had identified the basic problem of urban streams restorations, but many studies are based on knowledge an experiences obtained in restoration of waterways in rural areas, where the stressors affecting the streams and the responses of the aquatic ecosystems are different. Most of the earlier studies focused on long term results of restoration were conducted on streams affected by mining activity or discharge of toxic substances. The applicability of such results to the urban streams restoration is very limited.

Presently, the chemical and toxicological effects on waterways are minimized by high requirements on waste water treatment efficiency and construction and operation of sewer system. The construction of sewer system prefers separated sewer or, in case of combine sewers, reconstruction of combine sewer overflows to maintain minimal impact of the overflows water on the recipient. The current pollution control address dominantly the source, therefore the main goal of the urban streams restoration is not the elimination of chemical impact, but successful management of streams affected by input of big volume of storm water from the sewer system due to increasing impervious areas. The changes in impervious surfaces are the driving factor affecting streams in urban areas and causing degradation of the waterways. Numerous studies [1][17][40][49][48][49] had proved that stormwater is a main negative factor affecting urban creeks, and they also showed that restoration at local scale focused on increasing diversity of habitats typically does not bring the anticipated improvement of the biodiversity. Restoration of the waterways focused on removal of primary causation located in the catchment provides better results [1][40][48][49]. A combination of applied measures in catchments together with rehabilitation of the channels and bank areas is more successful and sustainable. Although the importance of the catchment processes for restoration is well known, it is still neglected. This marginalization leads to the overuse of end –of- pipe -strategies for stormwater management. These strategies apply measures such as retention, sedimentation reservoirs, ponds and artificial wetlands directly on the waterway or sewer system. Application of these measures is often carried out without good understanding of the basic processes between hydrological changes and biota (hydraulic stress for biota, periodicity of flood occurrence, periodicity of pollutants load, etc.). In many cases, application of these measures achieved a decrease of the maximal flow and a transformation of the flood [45], but the stress for biota did not decrease. The end- of- pipe- strategies do not preserve the natural periodicity of floods, and although they maintain a lower runoff during the rain event, they do not change the anthropogenic induced periodicity of flood [47][49].

The restoration of Zatišský creek from 70th of 20 century is an example where measures were focused on stabilization of the channel without any understanding of the reasons of the extreme erosion. Today, the creek is characterized by high level of erosion (Fig 6), which avoids development of any diversified biota. In such a case, it would be more efficient to apply measures to control hydrological conditions in the stream - decrease the amount of water entering the creek from storm water drains and hence decrease the erosion potential [23] through retention or infiltration of storm water in the catchment.

Fig.8 Erosion of Zátišský creek

Habitats of urban creeks are often simplified by technical measures leading to improvement of hydraulic operation of the channel and flood prevention. Some authors [1][47] recommend as a first step of waterway restoration to decrease the effective impervious areas. Instead of direct drainage of storm water to creek they propose retention and local use of the storm. Application of such measures may be followed by rehabilitation of the creek channel, leading to a greater diversification of habitats.

Remediation of stormwater impacts can be most likely achieved through widespread application of innovative approaches to drainage design. A critical factor in restoration and conservation of urban streams and their catchments is the human population [1], suggesting that an effective management of these streams will require a broader perspective beyond the traditional stream ecology. This perspective includes social, economic, and political dimensions [48].

The restoration of urban streams cannot return the streams back to the natural status, but it should ensure the recovery of the basic functions of the ecosystem. It is therefore necessary to define and acceptable status of the particular waterway, meeting the needs of the local community and the aquatic ecosystem. The influence of local community on the restoration seems to be an important social aspect. Schauman and Salisbury [40] proved that heavily modified urban creeks have negative effect on local inhabitants. The study also showed, that a waterway restoration which is not in agreement with requirements of the local community is not long-term sustainable.

6 CONCLUSIONS

Urban streams are essential part of urban life and deserve sufficient attention. We should no more think about them as means of waste and storm water drainage, but instead we need to understand them as integral part of the urban environment. With the respect to decades of deterioration of urban waterways´ ecological status, it is a long way to bring waterways to conditions allowing their use as place for recreation. Restoration is the only way to achieve good ecological status of the waterways. It is necessary to understand, that restoration of urban creeks needs to follow different rules than restoration of creeks in rural areas. Restoration of channels of urban creeks and rehabilitation of physical habitats for aquatic biota will not provide the expected increase of biodiversity, if the reason for its lowering was different from depression of habitats complexity and uniformity. In most cases the real reasons of bad ecological status of urban streams are floods induced by runoff from impervious surfaces due to progressing urbanization. The possible solution is to decrease effective imperviousness and application of measures increasing retention and later local use of the water. Finally, the restoration of urban creek is not possible without good understanding and communication between engineers, architects, city planner and natural scientists.

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8 CURRICULUM VITAE

DOC. RNDr. DANA KOMÍNKOVÁ, Ph.D.

Qualification:

- March 2007- habilitation in the field of Water management and water construction, CTU in Prague
- 2001-PhD. Institute for Environmental Studies, Faculty of Science, Charles University, Prague
- 1995-M.S. „Magistri in rerum naturae tutela“ Institute for Environmental Studies, Faculty of Science, Charles University, Prague

Employment:

- 2000- 2007- Lecturer, Laboratory of Ecological Risk in Urban Drainage, Faculty of Civil Engineering, Czech Technical University in Prague
- 2007 – to present- Associate professor Department of Sanitary and Ecological Engineering, Faculty of Civil Engineering, Czech Technical University in Prague

Teaching experiences:

- 1997-1998-Teaching assistant in aquatic chemistry Institute for Environmental Studies, Faculty of Science, Charles University, Prague
- 2000 to present- Teacher for undergraduate lectures of Environmental Toxicology, Ecology of urban watersheds, Chemistry- Faculty of Civil Engineering, Czech Technical University in Prague
- 2010 to present – Ecology of urban areas - Institute for Environmental Studies, Faculty of Science, Charles University, Prague
- Introducing a new subject –Ecotoxicology and Ecology of urban watersheds

International experience:

- 1993- short term scholarship University Hamburg (Germany)

- 1998-1999 scholarship from „Eidgenössiche Stipendienkommission für Ausländische Studierende“, EAWAG/ETH Switzerland
- 2000-sholarship from Soroptimist Foundation to participate in International Program of Tahoe Baikal Institute, USA and Russia
- 2001, 2002 -postdoctoral scholarship University of California, Davis, USA
- 2004 – University of Newcastle upon Tyne (UK) – visiting researcher
- 2005-2006 – University of Canberra, Cooperative Research Center for Freshwater Ecology (Australia)

Areas of interest

- 2000- present
    - Syndrome of urban streams- effect of urban drainage on ecological status of urban creeks – sustainable restoration, assessment of ecological status, proposal of measures
    - Fate of toxic metals in aquatic ecosystems
- 1998-1999 Microbial decomposition of *Phragmites australis*
- 1996-to date Fate of heavy metals in river sediments (PhD thesis)
- 1995-1996 Interaction of nutrients and toxic substances and their effect on aquatic organisms
- 1990-1995 Eutrophication of surface waters, particularly with respect to drinking water reservoirs (Diploma thesis)

Publications activity:

- Author or co-author over 100 research publication - 3 chapters in international book, 8 in impact journals, 23 on international conferences, 13 in Czech journals, 63 on Czech conferences
- 79 international citation on Web of Knowledge
- 1 university mimeographed

Reviewer activity:

- Review for grant agencies: Czech grant agency (GAČR) and Grant agency of Academy of Science (AVČR)

- Review for journals: Water Quality Research Journal of Canada, Journal of Environmental Science and Health, Journal of Hazardous Materials, Environmental Science & Technology , International Journal of Sociology and Anthropology, Environmental Monitoring and Assessment, Ecotoxicology

Scientific education

- 6 Ph.D. students (2 successfully defended their thesis)
- 12 diploma students (10 successfully defended)
- 1 diploma student winner of the Czech-Slovak Student Competition (SVOČ -2011)

Other activity

- Member of Ph.D. committee Faculty of Civil Engineering, CUT
- Authorized expert in the field of water management, speciality protection of water bodies, assessment of ecological risk and impact on water bodies and aquatic ecosystems
- Member of IWA
- Member of CzWA
- Member of editorial board
    - The Open Environmental and Biological Monitoring Journal
    - Listy CzWA