INTERACTIONS OF AN IMPOUNDED STREAM WITH URBAN DRAINAGE

G. Stastna, I. Kabelkova, J. Nabelkova and D. Stransky

Czech Technical University, Faculty of Civil Engineering, Department of Sanitary and Ecological Engineering, Thakurova 7, 166 29 Prague 6, Czech Republic, stastnag@lermo.cz

ABSTRACT

This paper presents a study of an urban stream affected by a reservoir with intermittent hydropower production and by a combined sewer overflow (CSO), which went through several reconstruction phases in the past years. Changes of the benthic community structure (BCS) caused by the reservoir and by the CSO as well as heavy metals concentrations in the stream sediment were followed to assess benefits of the CSO reconstruction. The final reconstruction phase of the CSO structure in 2005 brought a significant reduction of acute and chronic pollution and of hydraulic stress in the stream. As a result heavy metals concentrations in the stream sediment below the outlet decreased in 2006, however, no improvement of the BCS was observed as the community is already seriously degraded due to the Hostivar Reservoir impacts (stream connectivity disturbance, water quality changes). The impacts are augmented by the release of fine suspended solids from the reservoir related closely to the electricity production by the turbine on bottom outlets. The fine sediments discharged both from the reservoir and the CSO83 impose the same stressor on the benthic community in the stream. Thus, the benefits of the CSO83 reconstruction are overwhelmed by the detriments of the energy production by the Hostivar Reservoir.

Key words: Heavy metals, Macrozoobenthos, Reservoir, Urban drainage, Water quality

1. INTRODUCTION

Urban streams serve many functions: they are used as recipients of treated as well as untreated wastewater from wastewater treatment plants and from the sewer system, reservoirs built on them ensure flood protection, water supply, electricity production and recreation. Some of these services are complementary; however, some of them may be contradictory. At the same time an increasing accent is put on the protection of surface waters as ecosystems, i.e. living space for plants and animals (Directive 2000/60/EU).

This paper presents a study of interactions of a reservoir on an urban stream with a combined sewer overflow (CSO), which went through several reconstruction phases in the past years. Changes of the benthic community structure (BCS) caused by the reservoir and by the CSO as well as heavy metals concentrations in the stream sediment were followed. Also data on water quality, reservoir operation and discharge were gathered to identify their influence on BCS in individual years. The main goal is to assess the benefits of the CSO reconstruction and possible conflicts between services provided by the reservoir and by the urban drainage system.

2. MATERIAL AND METHODS

2.1. Study area

The study stream was the Botic, Prague, Czech Republic, with a catchment of 135 km^2 and a total length of 33 km. The Hostivar Reservoir is located at km 15.7-13.4. It was built in 1964 for flood protection. Its maximum depth is 12 m, volume 1.3 million m^3 in summer and 0.8 million m^3 in winter. It is eutrophied as a consequence of high phosphorus loads. In summer increase in pH and water temperature and decrease in oxygen concentrations compared to the upstream water quality is observed (Kabelkova et al., 2005). Total suspended solids concentrations and organic pollution are usually slightly higher below the reservoir. Water quality in the Botic Stream has been monitored by a local watershed authority 6 times per year since 2001 (www.praha-mesto.cz) (Tab. 1). Typical dry weather discharge in the Botic Stream below the reservoir is 110 l/s. The major flood peak reached 41 m^3/s in August 2002.

Tab. 1: Water quality above and below the Hostivar Reservoir (parameters assigned to classes III –V according to the Czech standard ČSN 75 7221 (1990); other parameters were in classes I or II)

	class	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
above	**V**	-	TSS	-	-	NO_3	-
	IV	P	P, NO_3, TSS	P, TSS	P	P	P
	III	BOD, COD, TOC,NH_4,TSS	BOD, COD, TOC	BOD, COD, TOC, NO_3	BOD, COD, TOC	BOD, COD, TOC	BOD,COD,TOC, NH_4, NO_3, TSS
below	**V**	-	Mn	TOC, NH_4, P, Mn	-	COD	-
	IV	-	P	COD	-	TOC, NO_3	O_2, TSS
	III	BOD, COD, TOC,NH_4,P,Mn	O_2, BOD, COD, TOC	BOD, NO_3, TSS	BOD, COD, TOC,NH_4,P,Mn	BOD, P, TSS	BOD, TOC, NH_4, P, Mn

Since 2001 the reservoir has been used also for electricity production. Turbine on bottom outlets was in operation 04/2001-02/2003 and 09/2005-05/2006 (Tab. 2).

Tab. 2: Operation of the Hostivar Reservoir

Period	**Until 03/2001**	**04/2001-02/2003**	**03/2003-08/2005**	**09/2005-04/2006**	**Since 05/2006**
Electricity production	not installed	yes	turbine failure	yes	turbine failure
Reservoir outflow	overflow	bottom outlet	overflow + bypass on bottom outlet	bottom outlet	overflow + bypass on bottom outlet

The first (most upstream) CSO is situated 1.5 km below the Hostivar Reservoir (CSO83). The overflow structure has been reconstructed in the past years in five phases. The benefits of the individual CSO reconstruction phases in terms of pollution and hydraulic impacts on the Botic Stream were simulated by a computer programme REBEKA (Rauch *et al.*, 2002) for a 70 years' Prague rainfall series (Kabelkova *et al.*, 2007). Simulation results (Tab. 3) show a gradual decrease of the average number of overflows per year, overflow volume and duration as well as of the amount of suspended solids discharged. The average number of overflows possibly causing ammonia toxicity was reduced by half (from 9 to 4.9) already in phase II and nearly eliminated in phase IV (0.4). However, the overflow volume, amount of suspended solids with which heavy metals amounts can be correlated as well as hydraulic stress were not significantly reduced until the phase V in 2005.

Tab. 3: Reconstruction phases and performance of CSO83 (average values per year)

Phase	**I**	**II**	**III**	**IV**	**V**
Period	**Until 10/1997**	**11/1997-05/2002**	**06/2002-08/2003**	**09/2003-04/2005**	**Since 05/2005**
Throttling (l/s)	477	569	569	569	2300
Inhabitant equivalents	33178	33178	33178	13133	13133
Overflow volume (m^3)	16044	13510	Construction and manipulation with flows	12265	2059
Discharged TSS (kg)	2218	1830		1371	214
Overflow duration (h)	9.0	6.5		5.4	0.4
No. of overflows	22	18		17	3
No. of NH_3 toxic events	9.0	4.9		0.4	0.0
No. of hydraulic stress events	6.1	5.7		5.3	1.3

2.2. Macrozoobenthos

Benthic samples were collected by kick sampling at one site upstream the reservoir (km 17.2), two sites downstream of it (km 13.2 and km 12.9) and two sites below the CSO (km 11.8 and km 11.1) always in summer (Fig. 1). Sites at km 12.9, 11.8 and 11.1 were sampled since 1998, the other sites since 2003. All sites have similar morphological and hydraulic characteristics.

For taxons found numbers of individuals were counted and characteristics and indexes of the benthic community were calculated by software ASTERICS (2006). Until 2000 only information on Saprobity Index is available.

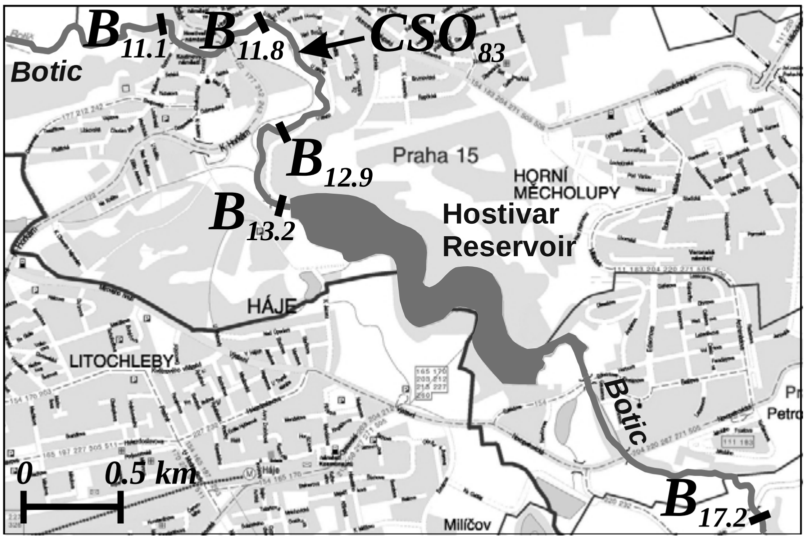

Fig. 1: Study area and monitoring scheme

2.3 Heavy metals in the sediment

Heavy metals concentrations (Cu, Zn, Pb) in the sediment were monitored at km 12.9, 11.8 and 11.1 several times per year since 1998. Sediment samples were dried in a lyophilisator and microwave digested with $HNO_3 + H_2O_2$. Heavy metals were analyzed by a flame atomic absorption spectrometer.

3. RESULTS AND DISCUSSION

3.1. Macrozoobenthos

BCS upstream of the reservoir is already seriously degraded. Average number of species found in 2003-2006 was 16±2, diversity 1.68±0.12 and Saprobity Index (Si) 1.66±0.22. The BCS changes in the individual years can be ascribed to the development after the major flood in 08/2002 when shredders were gradually replaced by grazers and scrapers, gatherers and filter feeders (Fig. 2).

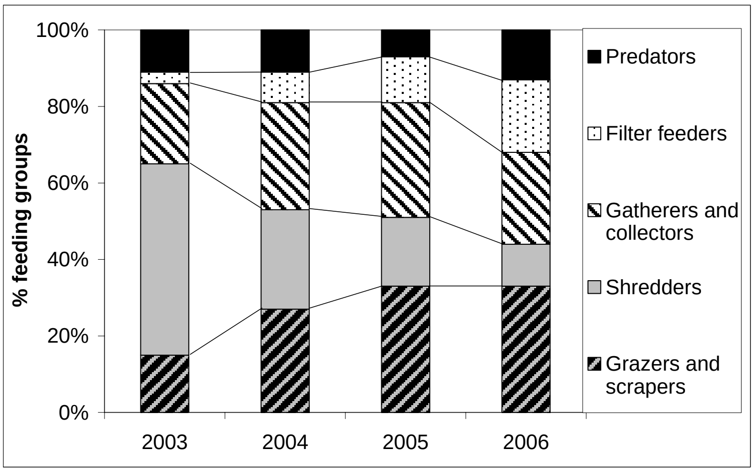

Fig. 2: Feeding groups distribution upstream of the Hostivar Reservoir (B17.2)

The Hostivar Reservoir caused a significant change in BCS. Immediately below the reservoir at km 13.2 the average similarity with BCS upstream was 46±12%. At km 12.9 the similarity increased slightly to 56±19%. Number of species dropped to 9±1 at km 13.2 and then increased to 14±3 at km 12.9. Zooplancton typical for the lentic habitat occurred whereas some benthic species (cased Trichoptera, Gastropoda or Coleoptera) almost disappeared. Average Si increased to 2.31±0.27 at km 13.2 and to 2.26±0.20 at km 12.9. The benthic community reacted on water quality changes and operation of the turbine (and with it related increased release of fine sediment). The highest number of benthic invertebrate species (Fig. 5) was found in 2004 with the best water quality (Tab. 1). Saprobity Index was 2.42±0.09 when turbine was in operation (2001, 2002 and 2006) whereas it was only 2.06±0.12 when the turbine was not installed yet (1998-2000) or was out of service (2004). The presence of fine particulate organic matter mirrors in the percentage of filter feeders (Fig. 3).

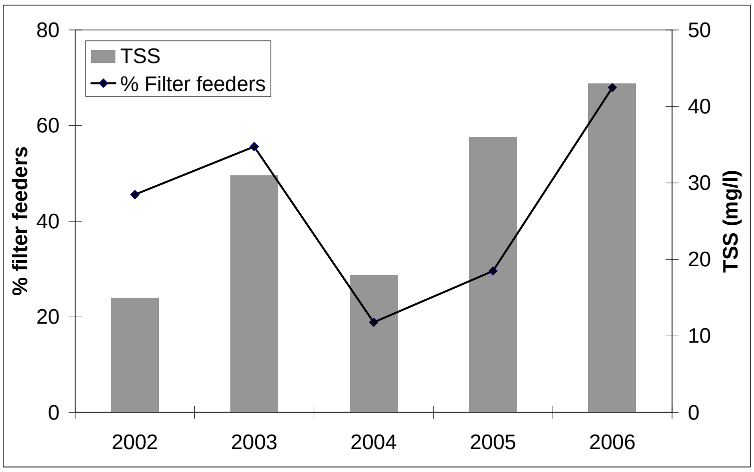

Fig. 3: Relation of filter feeders percentage to the average concentrations of suspended solids in spring and summer prior to macrozoobenthos sampling below the Hostivar Reservoir at B12.9

Downstream of the CSO the effects of the Hostivar Reservoir and of the overflows are mixed. In the years 1998 and 2000 (phase II) Si values at B11.8 were notably higher (by 0.2-0.4) than above the CSO reflecting thus the high number of overflows (Fig. 4). Since the 08/2002 flood the Si at km 11.8 had the same course as the upstream Si (correlation coefficient 0.98) and slightly lower values (in average by 0.16). Thus, since phase IV the overflows seem to have been reduced to a level exhibiting no detectable effect on the saprobity immediately below the CSO outlet. However, the number of species found at B11.8 was always significantly lower than at B12.9 and no benefit of overflows reduction can be seen (Fig. 5). The Si values at the more distant site B11.1 were very stable during the whole monitoring period (2.41±0.09). The benthic community at this site is almost unaffected by the overflows as the numbers of species at B12.9 and B11.1 were nearly the same and their average similarity index was 76±14% in the years after the flood.

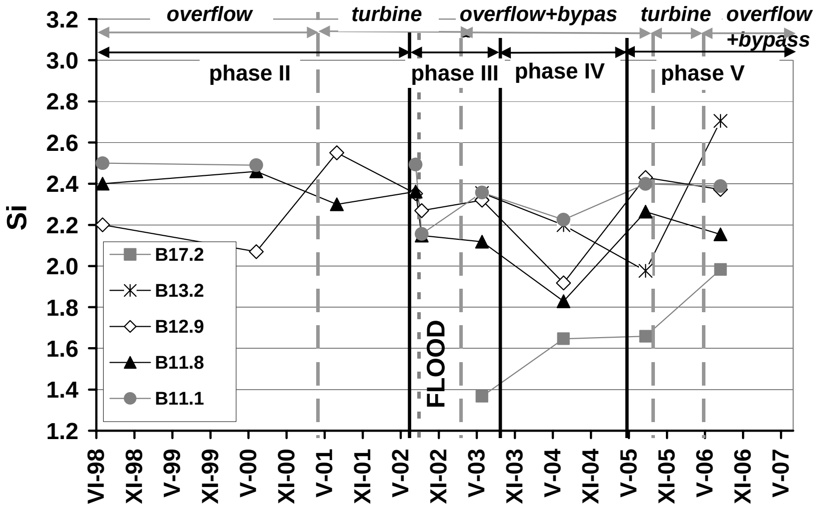

Fig. 4: Saprobity Index of macrozoobenthos

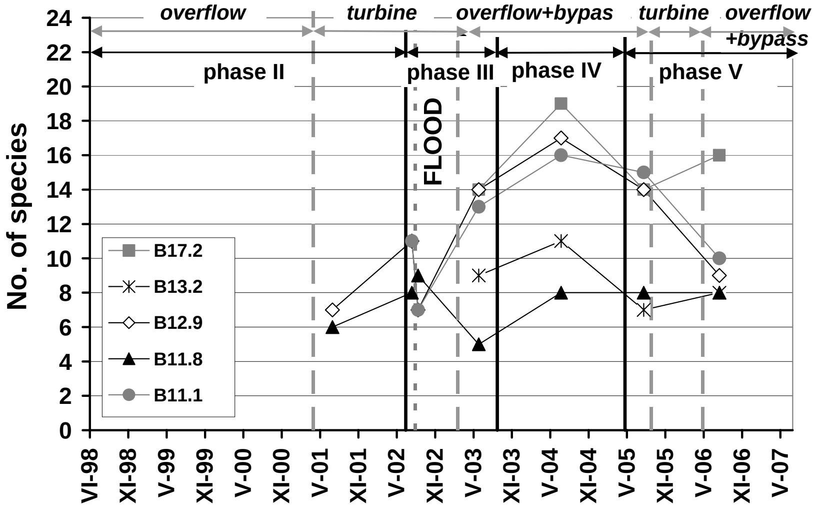

Fig. 5: Number of benthic invertebrate species

3.2. Heavy metals in the sediment

The courses of the concentrations of all three monitored heavy metals are similar (Fig. 6). In phase II the impact of the CSO was very pronounced. At km 11.8 below the CSO outlet 34.5x higher average concentrations of Cu, 4.8x of Zn and 5.8x of Pb than upstream of the CSO at km 12.9 were measured. At the more distant site km 11.1 these ratios were lower; however, background concentrations were exceeded as well (Cu 13.0x, Zn 3.2x, Pb 3.2x). After the flood in 08/2002 with massive bed erosion heavy metals concentrations below the CSO dropped to the upstream levels. Since then they oscillate reflecting individual overflow events and sediment scouring by minor floods. However, since 05/2005 (phase V) the ratios to the upstream concentrations decreased significantly, especially for Cu (the average ratios are: 5.7 for Cu, 2.9 for Zn and 4.6 for Pb at km 11.8; 9.2 for Cu, 2.4 for Zn and 2.7 for Pb at km 11.1).

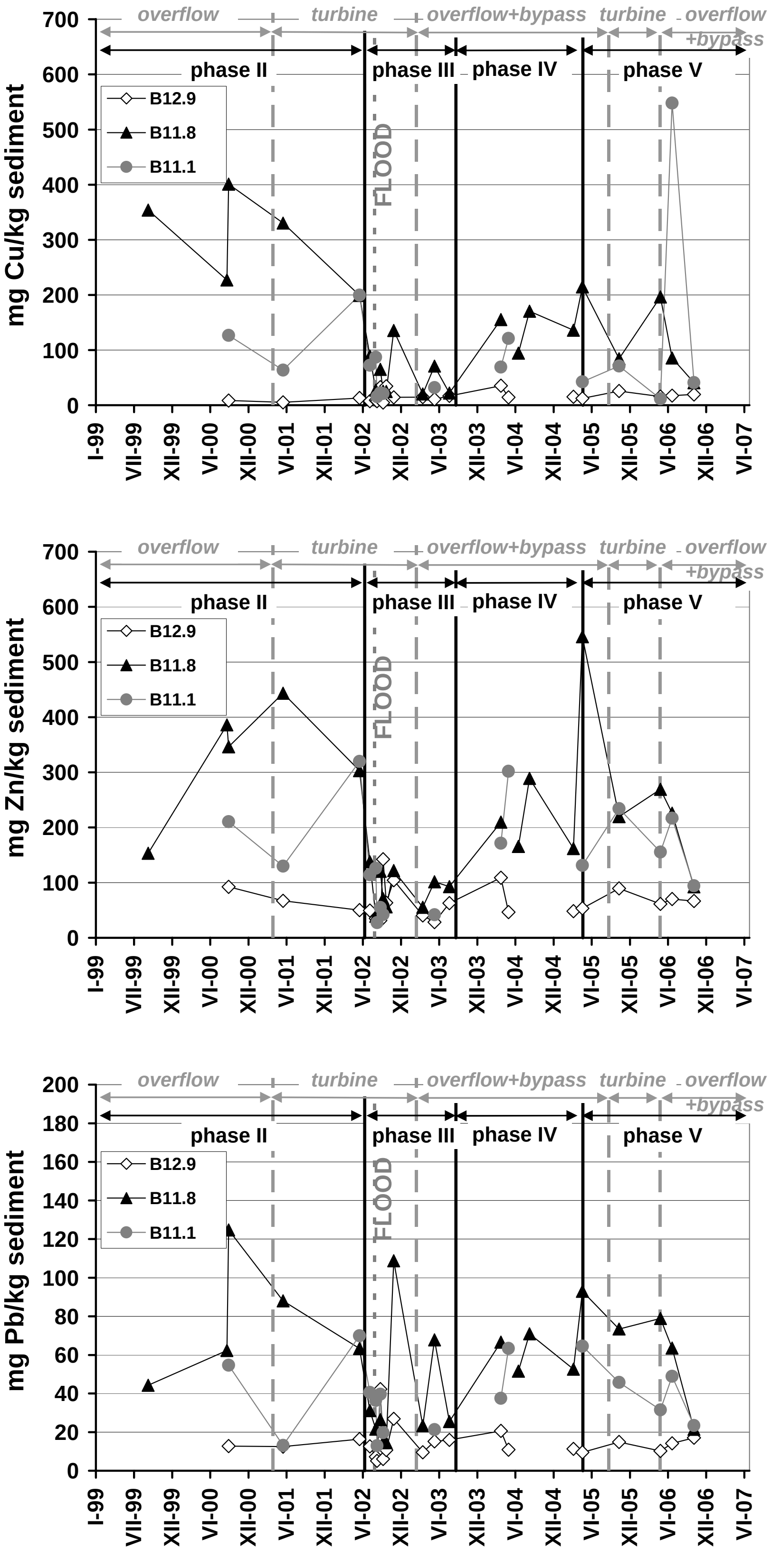

Fig. 6: Heavy metals concentrations in the sediment

4. CONCLUSIONS

The final reconstruction of the CSO structure brought a significant reduction of acute and chronic pollution and of hydraulic stress in the stream. As a result of this reconstruction heavy metals concentrations in the stream sediment below the outlet decreased in 2006, however, no improvement of the benthic community structure was observed as the community is already seriously degraded due to the Hostivar Reservoir impacts.

The reservoir disrupts the stream natural connectivity, changes composition of drifting benthic species and alters physical-chemical parameters of water quality. Thus, the benthic community structure below the reservoir differs from that at upstream reaches and recovers only slowly (a distance of 1 km was not sufficient for its complete renewal) (Stastna *et al*., 2005). The impacts are augmented by the release of fine suspended solids from the reservoir related closely to the electricity production by the turbine on bottom outlets.

The fine sediments discharged both from the reservoir and the CSO83 impose the same stressor on the benthic community in the stream. The upper tolerance level for suspended sediment of 10-15 mg/l (Griffiths and Walton, 1978) is highly exceeded already in the reservoir outflow. Thus, the benefits of the CSO83 reconstruction are overwhelmed by the detriments of the energy production by the Hostivar Reservoir.

Hydropower is considered to be “clean energy”. A question arises: Is it more sustainable to produce clean energy or to improve living conditions for macrozoobenthos? Both objectives are desirable, however, conflicting. Nevertheless, cancelling electricity production would bring only a partial improvement of the BCS as the reservoir itself can hardly be removed.

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