# Effect of reconstruction phases of the combined sewer overflow CSO83 on the ecological status of the Botic Stream, Czech Republic

L'impact des différentes étapes de la reconstruction du déversoir d'orage CSO83 sur l'état écologique du ruisseau Botic en République Tchèque

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## RESUME

La reconstruction du déversoir d'orage CSO83 a été réalisée en cinq étapes. On note une augmentation notoire des concentrations de métaux lourds retrouvées dans les sédiments du ruisseau Botic pendant la II. étape (Cu 34.5 fois, Zn 4.8 fois, Pb 5.8 fois). Elles ont ensuite baissé sur une brève période, ce phénomène est du fait de l´ablation du sédiment pendant la crue survenue en août 2002. Elles augmenteraient donc avec les différents déversements ou baisseraient selon que les débits augmentent. Lors de la IV. étape, l'élévation de la concentration est inférieure (Cu 6.0 fois; Zn 3.4 fois; Pb 4.5 fois). L´index Saprobity des macrozoobenthos réagit plutôt bien avec la qualité de l´eau du réservoir de Hostivar (proprement parlant, la concentration des matières en suspension) qu´avec les changements du CSO83.

## ABSTRACT

Combined sewer overflow structure CSO83 has been reconstructed in five phases. In phase II heavy metals concentrations in the sediment below the CSO83 were very high compared to upstream concentrations (Cu 34.5x, Zn 4.8x, Pb 5.8x). During a major flood in August 2002 with massive bed erosion the concentrations dropped to the upstream levels. Since then they have been oscillating and reflecting input by overflow events on the one hand and output by sediment scouring by minor floods on the other hand. However, since phase IV the ratios to the upstream concentrations are lower (Cu 6.0x, Zn 3.4x, Pb 4.5x). Saprobity Index of macrozoobenthos reacts rather on the water quality below the Hostivar Reservoir (especially suspended solids concentrations related to the reservoir operation) then on the changes at the CSO83.

## KEYWORDS

Heavy metals, Macrozoobenthos, Urban drainage, Water quality.

# 1 INTRODUCTION

The motivation to write this paper was a quite rare possibility to combine data on gradual changes of a combined sewer overflow structure performance and results of a long-term monitoring of the ecological status of an adjacent stream reach providing information on the efficiency of the measures adopted.

# 2 MATERIAL AND METHODS

## 2.1 Study area

Combined sewer overflow CSO83 is the first overflow structure at the Botic Stream, Czech Republic, located 1.5 km below the Hostivar Reservoir.

The Hostivar Reservoir was built in 1959-1962 in order to protect the downstream area from flooding. Since 2001 the reservoir has been used also for electricity production by a turbine on bottom outlets ($Q_{max}$ ≈ 200 l/s). In case of the turbine failure part of the dry weather flow is discharged through a bypass pipe on the bottom outlet ($Q_{max}$ = 66 l/s), the rest through the overflow (Tab. 1). Typical dry weather flow in the Botic Stream below the reservoir is about 110 l/s. However, the discharge during the major flood in August 2002 amounted up to 41 $m^3$/s. The highest discharge in the following years was 8 $m^3$/s in 02/2006, other peaks reached maximum 4 $m^3$/s.

| **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 |

Table 1: Operation of the Hostivar Reservoir

Water quality in the stream below the Hostivar Reservoir is monitored by a local watershed authority 6 times per year since 2001 (www.praha-mesto.cz). In 2001 and until the August flood in 2002 water quality was in class III (out of five classes of the Czech standard ČSN 75 7221) because of increased concentrations of BOD, COD, TOC, $NH_4$, P and conductivity. At the end of 2002 water quality deteriorated to class IV (high concentrations of TOC) and in the very dry year 2003 down to class V (high concentrations of TOC, $NH_4$, P and Mn). In 2004 water quality improved to class III again. However, in 2005 several values of COD and TOC were measured in class IV again. In 2006 all parameters belonged at least to class III except for dissolved oxygen which dropped during the extremely hot summer months to class IV.

## 2.2 Phases of reconstruction of CSO83

The overflow structure has been reconstructed in the past years in several phases. Changes of the throttling, accompanying increase of the critical discharge $Q_{crit}$ when the overflow begins, changes in the catchment as well as overflow hydraulic characteristics monitored or calculated by the Prague Water Supply and Sewerage Company (2000, 2005) and the General masterplan processor (Hydroprojekt and DHI Hydroinform, 2001) are summarized for the individual phases in Tab. 2.

<table>
<tr><th>Phase</th><th>I</th><th>II</th><th>III</th><th>IV</th><th>V</th><th>VI</th></tr>
<tr><td>Period</td><td>Until 10/1997</td><td>11/1997-05/2002</td><td>06/2002-08/2003</td><td>09/2003-04/2005</td><td>Since 05/2005</td><td>Outlook 2010</td></tr>
<tr><td>Throttling</td><td>DN500</td><td>DN500 +DN300</td><td>DN500 +DN300</td><td>DN500 +DN300</td><td>Special cross section</td><td>Special cross section</td></tr>
<tr><td>Changes in the catchment</td><td></td><td></td><td rowspan="7">Transitional period of construction and manipulation with flows</td><td>Divertion of part of the catchment</td><td></td><td>Emergency outlet only</td></tr>
<tr><td>$Q_{crit}$ (l/s)</td><td>477</td><td>569</td><td>569</td><td>2500</td><td>5200</td></tr>
<tr><td>$Q_{hmax}$ (l/s)</td><td>136</td><td>136</td><td>53</td><td>53</td><td>53</td></tr>
<tr><td>$Q_{24}$ (l/s)</td><td>96</td><td>96</td><td>37</td><td>37</td><td>37</td></tr>
<tr><td>Dilution</td><td>1+2.5</td><td>1+3.2</td><td>1+14.4</td><td>1+46</td><td>1+101</td></tr>
<tr><td>No. of overflows monitored</td><td>34/ 5 m. 05-09/ 1997</td><td>18/ 6 m. 05-10/ 1999</td><td>10/ 3 months 06-08/ 2004</td><td>2/ 2m. 05-06/ 2005</td><td></td></tr>
<tr><td>$Q_{maxoverflow}$ monitored ($m^3$/s)</td><td></td><td>5.2</td><td>5</td><td>0.9</td><td></td></tr>
</table>

Table 2: Changes at the CSO83 and hydraulic characteristics

## 2.3 Simulation of pollution and hydraulic impacts of the CSO83 on the Botic Stream

In order to assess benefits of the individual CSO reconstruction phases, pollution and hydraulic impacts of the overflows on the Botic Stream were simulated by a computer programme REBEKA (Rauch et al., 2002) for a 70 years' Prague rainfall series. REBEKA simulates both emissions from the sewer system (discharge of water, total suspended solids and $NH_4$-N) as well as immissions in the receiving water (frequency of acute water pollution events caused by unionised ammonia $NH_3$ by comparison of simulated doses for each overflow event against defined threshold toxicity values and frequency of hydraulic stress events by comparison of actual bottom shear stress to the critical bottom shear stress for erosion calculated with Meyer-Peter formula).

The urban catchment impervious area is 25 ha. Wastewater dry weather flow was taken from Tab. 2 as $Q_{24}$. Stream discharge was considered 110 l/s. Water quality input data originate from own measurements (Kabelkova et al., 2005) (wastewater: $NH_4$-N = 26 mg/l, alkalinity = 3 mmol/l, pH = 8, TSS = 200 mg/l, stream water: $NH_4$-N = 0.3 mg/l, alkalinity = 2 mmol/l, pH = 8.5, T = 5-25°C). Sediment transport was calculated with values I = 0.006, n = 0.040 $s/m^{1/3}$, $d_{50}$ = 24 mm (Stastna, 2005).

## 2.4 Monitoring of the ecological status of the Botic Stream

The ecological status of the Botic Stream was followed by monitoring of heavy metals concentrations in the sediment and of macrozoobenthos since the year 1998 (1998-2000 in the framework of a pilot project for the General masterplan (LERMO, 2000), since 2001 in two PhD. theses (Nabelkova, 2005, Stastna, 2005)). One sampling site (B12.9) was located upstream of the CSO83 and two sites (B11.8 and B11.1) downstream of it (100 and 800 m) (Fig. 1). All sites have similar morphological and hydraulic characteristics.

Sediment samples were collected several times per year, dried in a lyophilisator and microwave digested with $HNO_3$ + $H_2O_2$. Heavy metals (Cu, Zn, Pb) were analyzed by a flame atomic absorption spectrometer.

Macrozoobenthos was collected in summer by kick sampling and determined in the laboratory. For taxons 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.


Figure 1: Monitoring scheme

# 3 RESULTS AND DISCUSSION

## 3.1 Pollution and hydraulic impacts of the CSO83 on the Botic Stream

Simulation results 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 in the individual reconstruction phases. 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.

| **Phase** | **I** | **II** | **IV** | **V** | **VI** |
|---|---|---|---|---|---|
| **Period** | **Until 10/1997** | **11/1997-05/2002** | **09/2003-04/2005** | **Since 05/2005** | **Outlook 2010** |
| **$Q_{crit}$ (l/s)** | 477 | 569 | 569 | 2300 | 5200 |
| **Inhabitant equivalents** | 33178 | 33178 | 13133 | 13133 | 13133 |
| **Overflow volume ($m^3$)** | 16044 | 13510 | 12265 | 2059 | 210 |
| **Discharged TSS (kg)** | 2218 | 1830 | 1371 | 214 | 21 |
| **Overflow duration (h)** | 9.0 | 6.5 | 5.4 | 0.4 | 0.0 |
| **No. of overflows** | 22 | 18 | 17 | 3 | 0 |
| **No. of $NH_3$ toxic events** | 9.0 | 4.9 | 0.4 | 0.0 | 0.0 |
| **No. of hydraulic stress events** | 6.1 | 5.7 | 5.3 | 1.3 | 0.3 |

Table 3: Results of simulations with REBEKA (average values per year)

## 3.2 Heavy metals in the sediment

The courses of the concentrations of all three heavy metals are similar (Fig. 2). Concentrations upstream of the CSO83 (B12.9) were low (in average 16 mg Cu/l, 64 mg Zn/l, 14 mg Pb/l) and considered to be background.

The impact of the CSO83 was very pronounced especially in phase II. At the site B11.8 100 m 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 were measured. At the more distant site B11.1 these ratios were lower; however, background concentrations were exceeded as well (Cu 13.0x, Zn 3.2x, Pb 3.2x). After a major flood in 08/2002 accompanied by a significant sediment transport heavy metals concentrations below the CSO dropped to the upstream levels. Since then the concentrations oscillate and reflect individual overflow events on the one hand (e.g. in 04/2005 the very high concentrations are due to the sampling one day after the overflow) and sediment scouring by minor floods on the other hand. Since 2004 (phase IV) some of the concentrations reached the pre-flood values, however, the average elevation is lower, especially for Cu (Cu 6.0x, Zn 3.4x, Pb 4.5x at B11.8; Cu 7.9x, Zn 2.5x, Pb 3.2x at B11.1). In 2006 (phase V) the concentrations seem to have a decreasing tendency.

## 3.3 Macrozoobenthos

The benthic community upstream of the CSO83 reacts visibly on the water quality below the Hostivar Reservoir and on the operation of the reservoir (especially on release of fine sediment by bottom outlets when the turbine is in function). Saprobity Index (Si) (Fig. 3) at B12.9 increased from 2.07 to 2.55 after the turbine was installed in 2001 and stayed high until 2003 when water quality was in class IV. The major flood in 08/2002 brought only a slight reduction of Si from 2.35 to 2.27. In 2004 the turbine was out of operation and both water quality and Si improved (Si = 1.92). In 2005 the Si reflected again the water quality deterioration below the reservoir (Si = 2.43). In spite of a general water quality improvement in 2006 the Si improved only slightly to 2.37 as the turbine was in function until 05/2006 when the benthic community was already affected by increased presence of fine suspended solids. The highest number of benthic invertebrate species (Fig.4) was found in 2004 with the lowest average concentration of suspended solids in spring and summer prior to the macrozoobenthos sampling (2003: 32 mg TSS/l, 2004: 18, 2005: 36, 2006: 43). The presence of fine particulate organic matter mirrors in the percentage of filter feeders (56% in 2003, 19% in 2004, 30% in 2005, 68% in 2006).

Downstream of the CSO83 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 CSO83 reflecting thus the high number of overflows. In 2001 and before the flood 08/2002 Si at B11.8 stayed more or less constant, although the benthic community structure at B12.9 deteriorated. Since the flood causing a reduction of saprobity at B11.8 from 2.36 to 2.15, the Si at B11.8 has 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 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 (Fig. 4) and no benefit of overflows reduction can be seen.

The Si values at the more distant site B11.1 were very stable during the whole monitoring period (2.41±0.09 without the post-flood value 2.16). The benthic community at this site is almost unaffected by the overflows as the numbers of species at B12.9 and B11.1 are nearly the same (Fig. 4) and the average similarity index of these two sites has been 76% since the flood.

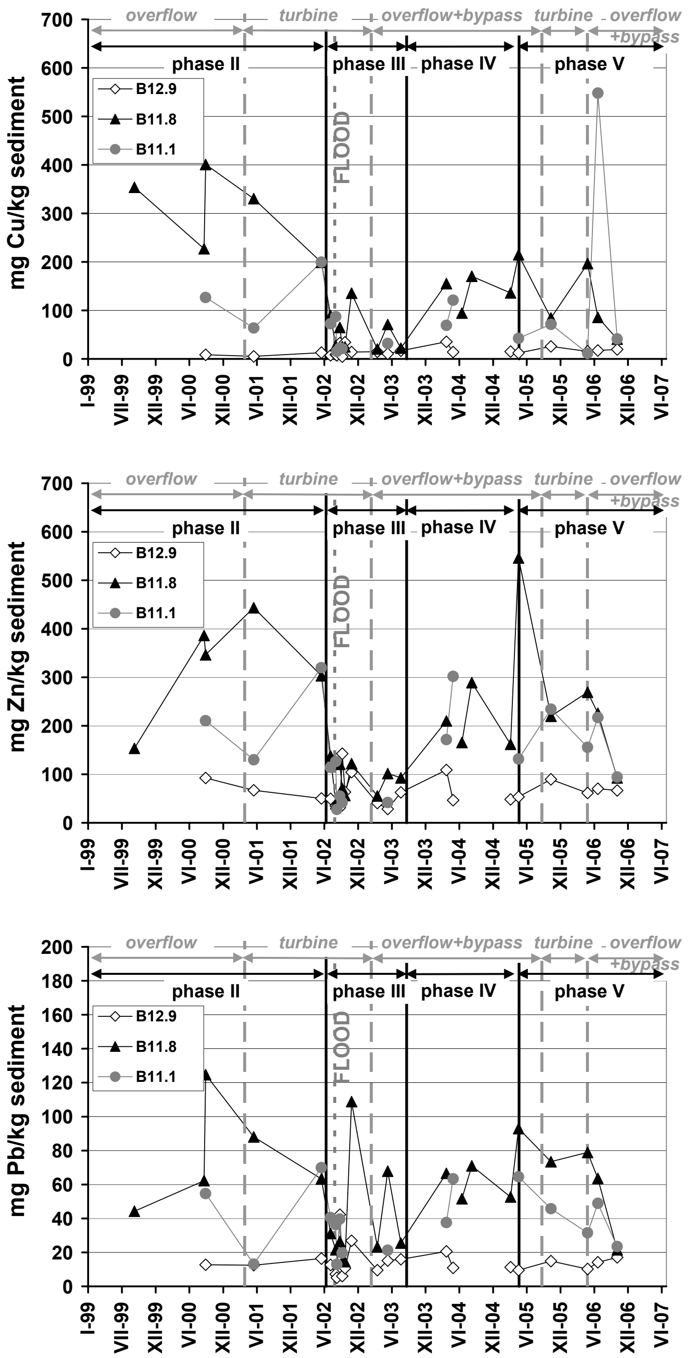


Figure 2: Heavy metals concentrations in the sediment

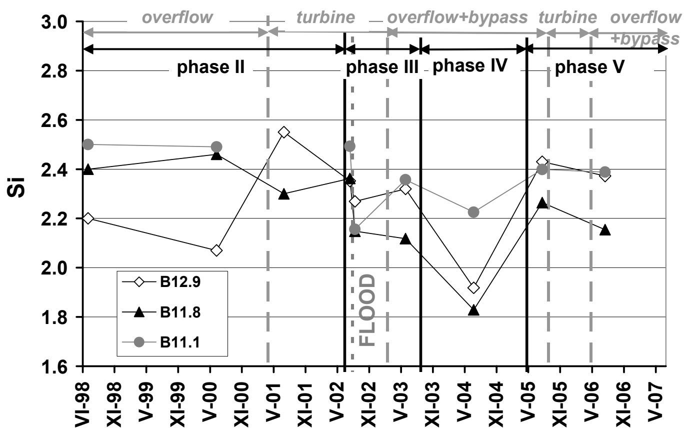


Figure 3: Saprobity Index of macrozoobenthos

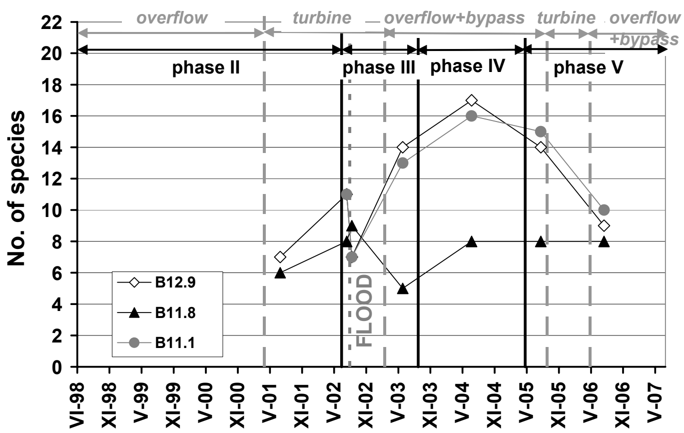


Figure 4: Number of benthic invertebrate species

## 4 CONCLUSIONS

The gradual reconstruction of the CSO83 structure and especially its final phase in 05/2005 brought a significant reduction of both acute and chronic pollution impacts and of hydraulic stress in the Botic Stream. It has resulted in a decrease of heavy metals concentrations in the sediment (especially Cu) below the outlet. However, no improvement of the benthic invertebrate community structure has been observed downstream yet.

The heavy metals input and output seem to be balanced so far. Nevertheless, it depends to a very large extent on the rainfall depth and on the hydrological regime below the Hostivar Reservoir in individual years.

Overflows used to deteriorate the biological status downstream of the CSO83 when the upstream biological status was good. However, since the year 2001 after the turbine on the bottom outlets of the Hostivar Reservoir has been taken into function, the benthic community structure below the reservoir has deteriorated. The benthic community structure is highly affected by the release of fine sediment from the reservoir which can be partly related to the changes of the reservoir inflowing water quality, partly to the way of the reservoir operation.

Benthic invertebrate have a very low upper tolerance level for suspended sediment of 10-15 mg/l (Griffiths and Walton, 1978). Increases in suspended solids of 20-80 mg/l above normal levels caused a 45-70% reduction in total numbers of benthic invertebrate (Gammon, 1970) due to increased drift. The reduction of benthic species numbers observed in this study was 20% when average TSS concentration increased from 18 to 36 mg/l and 47% when the increase continued to 43 mg/l.

The fine sediments discharged both from the reservoir and by the CSO83 impose the same stressor on the benthic community in the stream. Thus, the benefits of the CSO83 reconstruction are overwhelmed by the changes of the water quality flowing out from the Hostivar Reservoir. Even in 2004 with the best water quality the benthic community below the reservoir consisted mainly of highly tolerable species and the impact of CSOs was only local to the distance of about 400 m (Stastna, 2005).

The general conclusion is that the assessment of the potential of protective measures in the urban drainage system aiming at the improvement of the stream ecological status requires information on more complex relationships in the catchment than the sewer system performance only. The emission based approach might indicate a considerable improvement; however, the reality may differ.

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