METHODOLOGY OF ECOLOGICAL DISCHARGES ASSESSMENT IN SMALL STREAMS IN URBAN ENVIRONMENT

Jana Caletkova[1], Pavel Fatka[1]

[1] Laboratory of Ecological Risk in Urban Drainage (LERMO),Faculty of Civil Engineering, Czech technical University in Prague, caletkova@lermo.cz

ABSTRACT

Urban streams impacted by storm sewer outlets or Combined Sewer Owerflows (CSO) present a serious and complex problem. The outlets and overflows affect organisms in urban streams usually by hydraulic, physical and chemical stress.
Instream Flow Incremental Methodology (IFIM) represents a possible approach, it includes biology with impact assessment and connects it with hydraulic aspects. The IFIM methodology is comprised of not only field monitoring, and experimental work, but also mathematical modelling of the water biota population development. Data obtained from field work are used as input and calibration data in mathematical simulations.
One of the important instruments of IFIM methodology is the computational tool Physical HAbitat SIMulation system (PHABSIM) used particularly for the modelling and prognoses of changes in a physical habitat depending on discharge variation with regard to macrozoobenthos species and their life stage.
Simulations in MOUSE (Modelling Of Urban Sewers) were done to understand run-off relations and their dependence on rainfalls in the watershed. MOUSE gave the hydraulic and hydrological input data for PHABSIM, and assessed the impact of sewer networks on aquatic biota.

KEYWORDS

Ecological discharge, Small streams, Macrozoobenthos, Monitoring, Sewer

INTRODUCTION

Adoption of the Directive 2000/06/ES leads to definition of a minimal ecological discharge in watercourses which enables organisms or their life stages fixed on waters good life conditions. Significant problems are connected with small urban streams impacted by outlets from storm sewer systems or CSO. Frequent outflows from sewer and discharge variation in the creek put a high demand not only on the watercourse but also on the aquatic biota.
Problems with the assessment of anthropogenic impact, especially sewer outlets as a main element of the drainage system in urban

catchment, were primarily concentrated on hydraulic and physical and chemical aspects. The biological assessment was not taken into account until nearly the last decade of last century.
The assessment of ecological discharges (minimum, maximum) usually came out of the basic demand to guarantee water quality declared primarily by chemical indicators. Other requirements or indicators were taken into account only for specific purposes (e.g . recreational or sports usage). From the ecological point of view, the assessment of pollution due to anthropogenic effect was limited only to the chemical water quality parameters.

Common biological aspect parameters are development, variability and stability of aquatic biota. Nowadays, there is a significant effort to implement this complex approach into water management.

One possibility, of how to include biological, hydraulic and morphological parameters in the complex assessment of the watercourse is - IFIM methodology which defines ecologically acceptable discharges in the watercourse and offers a suggestion of their optimal exploitation.

A main objective of the project was to determine the ecological discharge for macrozoobenthos living in small streams in urban environment.

METHODS

The IFIM methodology (Bovee,1998) was developed at the end of 60s of the last century. The IFIM is most often used for the determination of ecologically acceptable discharges in watercourses and for the design of handling regulations. Furthermore the IFIM can be used in the process of EIA (Ecological Impact Assessment) to minimise the ecological impacts of the hydraulic structures design and management.

The assessment based on IFIM comes from the real conditions in a particular watercourse. It is comprised of the requirements of species inhabiting the watercourse, their demands on their habitat during changes of discharge or changes in the surrounding environment. With the help of IFIM it is possible to carry out hydrological analyses, which allow the prediction of several scenarios and the determination of limits for the watercourse. In fact this approach gives a clear comparison and looks at different problems in a fluvial system. From the biological viewpoint it lays emphasis on the comparison of a usable habitat during a number of seasons to record variability in water supply and in habitat conditions. In the case of multipurpose exploitation of water sources during a dry weather period, a controlled regime of outlets contributes to compatibility between direct and indirect users of the watercourse and makes possible a quick restoration of the aquatic population during a period of favourable conditions.

One of the basic instruments of IFIM methodology is a simulation tool PHABSIM (Milhous, 1999). It is used for the modelling of changes of habitat with respect to changes of discharge and connected to the ecological consequence for particular species and their life stages. PHABSIM comprises of two main components: hydraulic and biological. The hydraulic part enables calculation of water levels using STGQ model. This model solves water levels as a regression between different water level stages and discharges. The calculation of velocity profiles is made with VELSIM model. As a primary input of the biological modelling Habitat Suitable Index (HSI) curves were used. HSI curves define a ratio between an appearance of particular macrozoobenthos species and a variable of microhabitat (water depth, flow velocity, substrate, possibility of hiding place etc.). It is necessary to develop HSI curve for each species separately.

The schematization of watercourse characteristics was required for both hydraulic and biological modelling. In the first step, the watercourse bed was divided into the separate cells. Each cell represents a characteristic section of the watercourse. Secondly all hydraulic and biologic parameters were measured in verticals of cross sections of the watercourse body. These measuring profiles pass through particular cell. Measured values were considered uniform for whole section of the watercourse. The measured hydraulic parameters in cells were water depth, flow velocity, type of substrate, water and bed levels and cross section area. The biological parameters were determined from samplings.

After the biological data treatment and the calibration of hydraulic software hydro-biological scenarios were calculated using HABTAE model. HABTAE is the part of PHABSIM model. Results from HABTAE are graphs of Weighted Usable Area (WUA). WUA represents an available area for particular biota or its life stage with regard to discharge changes.

The value for whole habitat is calculated as:

$$\text{TOTAL HABITAT} = WUA*L_c* L_s \qquad (1)$$

where L_c is a length of cell of characteristic section and L_s is a length of characteristic section.

WUA can be calculated according to several criterions. The most common criterion is particular suitability index for several environment parameters as water depth, flow velocity etc.

Calculation of WUA for one cell is :

$$WUA_{ci} = A_{ci}*(SId_i*SIv_i*SIs_i) \qquad (2)$$

Where A_{ci} is area of cell and SIx_i is particular Suitability Index.

And for whole watercourse one can write:

$$WUA = \Sigma\, WUA_{ci} \qquad (3)$$

The IFIM methodology was tested on urbanised Zátišský creek in Prague, the capital of Czech Republic. Whole creek but especially its middle section is strongly affected by erosion due to disproportion in discharge during rain events. There are eight outlets from the sewer system that practically devastate the creek bed along its whole length. During the dry weather period there is on the contrary very small discharge characterized with Q_{355} = 0,5 l/s. Zátišský creek is a tributary of the Vltava River. The length of the creek is 3,080 km, but hydraulic head is relatively high, about 83 m. The catchment's area is 3,022 km^2. The Zátišský creek is very variable stream.
The hydraulic-biological assessment was based on fieldworks in the area of interest. For modelling a broad amount of hydraulics, hydrological, morphological and biological data was required. Data were used as input for mathematical modelling and describe real condition in the creek. Particularly biological data were based on samplings of the benthos and following specification of water macrozoobenthos.
Zátišský creek was divided into three representative sections separated by retention basins. In the first step each of three parts was assessed individually, in second step the creek was assed as a whole. All the data necessary for calibration of PHABSIM and MOUSE was obtained from fieldwork and monitoring. Hydrological monitoring took place on both the creek and the outlets from the sewer system. Moreover, it gives balance volumes in the creek and sewers. Monitored values were the velocities and water levels for discharge calculation. Other measured values were cross section areas, water and bed slopes, vertical distribution of velocities in particular cell. Very detailed measurements were also made of the substrate. Biological data was collected by sampling.
As the most suitable indicator the benthic population was chosen. The taxonomy of macrozoobenthos is very well described (Rozkosny, 1980) and used for biological assessment of watercourses during the past few years. The macrozoobenthos organisms have limited mobility and they can be considered as fixed inhabitants of the substrate in a characteristic habitat. Macrozoobenthos also have a very good response to stress and worsening life conditions. Macrozoobenthos were examined in the laboratory after sampling in situ. For the sampling of macrozoobenthos the Kick sampling method was used (Kokeš,1999).

RESULTS AND DISCUSSION

First result from biological sampling is Habitat Suitability Index (HSI) for particular variables of habitat. HSI keeps standards of

Midcontinent Ecological Sciences Centre (Ritchie, 2000) to sample minimum 100 pieces of particular macrozoobenthos species and their life stage. Species with the highest representation was *Asellus aquaticus*. On the HSI graphs one can see relations between converted number of organisms and water depth, flow velocity and substrate. The most preferred velocity is 0,08 – 0,1 m/s, water depth 200 – 280 mm and substrate fraction 6 – gravel, sand (figure 1 – 3).

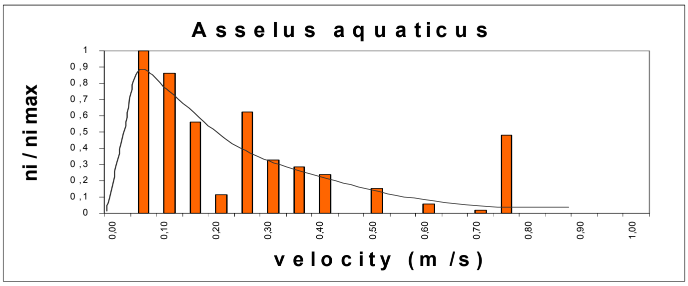

figure 1. Asellus auaticus – HSI for velocity of flow

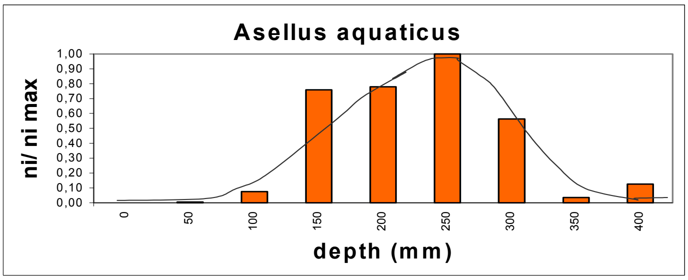

figure 2. Asellus aquaticus – HSI for depth

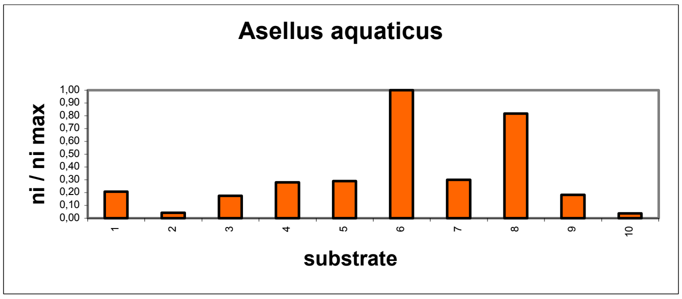

figure 3. Asellus aquaticus – HSI for substrate

Hydraulic simulation was made in STGQ software. Three different water stages were measured for proper calibration. Calibrated model did not differ from real values more than 2 cm. More difficult was calibration of velocities in model VELSIM (figure 4). The model did not calculate with discharges lower than 10 l/s. Unfortunately there were some parts on the creek with lower discharge.

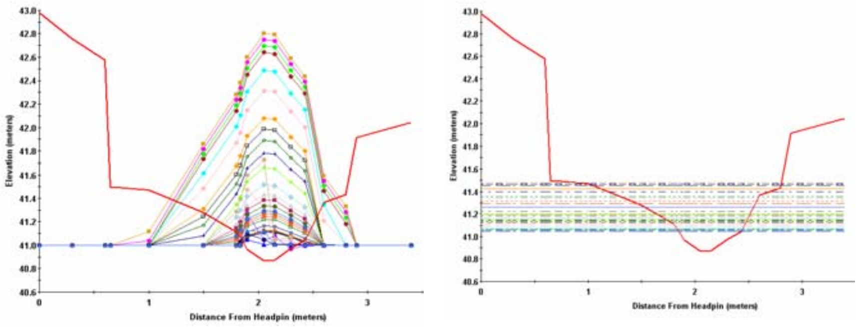

figure 4 - PHABSIM – results of flow velocities and depths calibration

The mathematical model of the watercourse was built in the real scale of lengths. The biological material was collected in 98 cells. The simulation program MOUSE (DHI,1994) was used for run off relations at the Zátišský creek (figure 5).

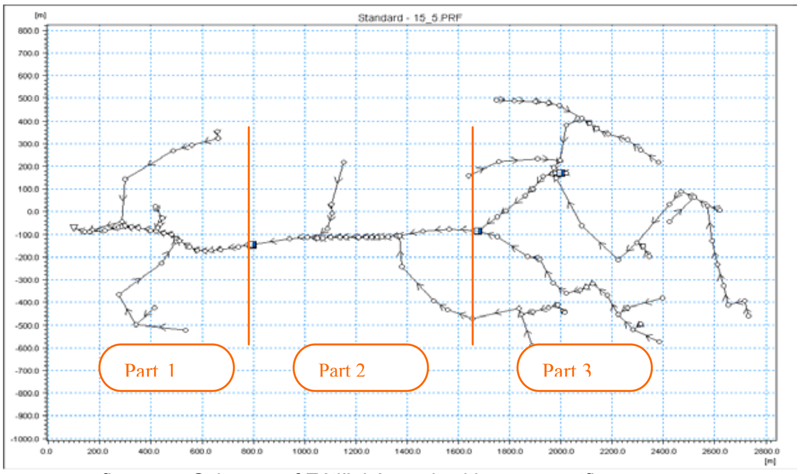

figure 5 - Schema of Zátišský creek with sewer outflow

It was necessary to calculate every part separately for better results. For a simulation of affected discharges, rains: 5;15;120 minutes, with their frequency 5;1;0.2 for a year, were chosen as representative. This choice includes common rains and extreme rains too. We were especially interested on maximal discharges in the single parts of the stream. The reason for this decision was the presumption that in the case of high discharges during big rain events, the shear stress on the stream bed, which is important for sediment movement, is exceeded. The observed benthos is directly connected to the sediment and in cases where the discharge is so big that the sediment starts to move, consequently the observed organisms are moved. In some cases the organisms are washed out even earlier than sediment.

On figure 6 the dependence of Weighted Usable Area on the discharge is evident. It varies between 0,01 – 1,8 m^3/s. From the WUA, which were generated for all present organisms, it was determined that every organism prefers a different range of discharges. It is ideal to find a range of optimal discharges, which would support the biggest number of species and support also the biological equilibrium in the stream. The results of all graphs indicated an optimum discharge of 40 – 50 l/s. 20% of maximum value of WUA was perceived as a limit of maximum discharge. This value represent a limit of discharge, for which recolonization of stream is still possible. For *Asellus aquaticus* this limit was present at 1,3 m^3/s. It is possible to use it this way only to imply maximum discharge. Unfortunately, during self simulation it was discovered, that the program PHABSIM refuses to calculate with a discharge smaller then 0,01m^3/s. For this reason is impossible use this method for the expression of the dependence of WUA on smaller discharges.

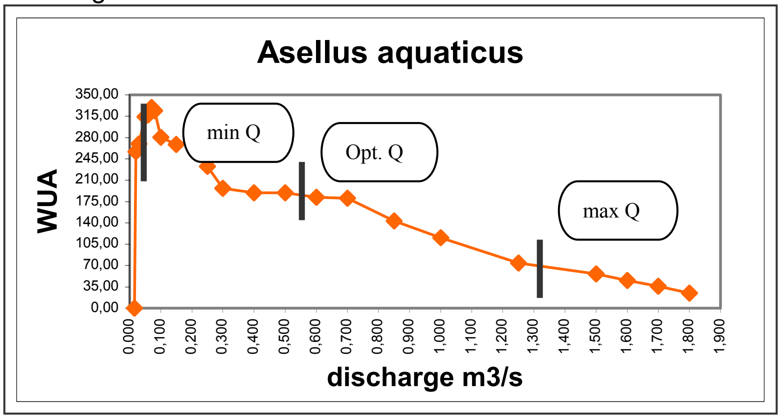

figure 6.- Asellus aquaticus - Weighted Usable Area

Discharges	Calculation
Q minimum	50 – 70% opt. Q
Q optimum	40 – 50 l/s
Q maximum	20% max. Q

table 1 – calculated discharges

part	Q 355	5min/5	5.I	5 / 0,2	15.V	15.I	15 / 0,2	120 / 5	120 / 1	120 / 0,2
part first	0,04	0,31	0,40	0,45	0,32	0,40	0,46	0,34	0,46	0,55
part second	0,03	1,34	1,50	1,80	1,35	1,50	1,70	0,98	1,20	1,30
part third	0,01	0,39	0,45	0,50	0,42	0,50	0,53	0,27	0,37	0,40

table 2 – monitored and simulated discharges

CONCLUSIONS

Using simulation tool PHABSIM its possible to make a uniform view on stream from hydraulic and biological point of view. The simulation showed, that PHABSIM is not able to give appropriate results for discharge smaller then 0,01 m^3/s. This program is an unsuitable tool for a determination of the minimal ecological discharges in streams with small discharges or the stream with small velocities of flow. In this case we will respect the opinion, that the minimum discharge should never fail below 50 –70% of the optimal discharge. This value was expressed by the range 0,02 – 0,038 m^3/s. The results of wet weather discharges simulation were in the range 0,27 – 1,8 m^3/s. The value, which expressed maximal discharge matches 20% maximum of value Weighted Usable Area for every organism. Required division of discharges was fulfilled in the first part. The maximum discharge was always exceeded in the second part by a rain event with durations of 5 min and 15 min. In the third part, m-day discharge was again smaller than Q min. This fact is due to a very small slope in this section. Some measures need to be employed in both cases (the second and third part), which enables the required range of discharges to be reached. The reconstruction and restoration of the channel is required in both sections. In the second part it is urgent to decrease the flow velocity and reduce the bed slope. This could be reached for example by the channel bed drops. Velocity of flow needs to be increased in the third part. We can achieve it for example by a change of substrate and subsoil. The manipulation regulations of all reservoirs should be improved and used in a both cases.

REFERENCES

Bovee K. D., Lamb C. J., Bartholow M., Stalnaker C. B., Taylor J. and Henriksen J.(1998-0004*). Stream Habitat Analysis Using the Instream Flow Incremental Technology*, U.S. Geological Survey, Biological Resourses Division Information and Technology Report USGS/BRD

DHI, (1994). *Hydraulic Institute user Manual and Reference Manual (MOUSE)*, DHI

Kokeš J., Vojtíšková D (1999) *Nové metody hodnocení makrozoobentosu tekoucích vod*, VÚV T.G.M. Praha

Mattas,D. et al. (1998). *Přírůstková metodologie proudění v toku (IFIM). Metodický návod;* VÚV T.G.M. Praha

Milhous, R. T.,(1999). *Nose velocities in physical habitat simulation IN Hydraulic Engineering for Sustainable Water Resources Management at the Turn of the Millenium.* Proceedings of the XXVIII IAHR Congress, 22-27 August 1999.: Graz, Austria, Technical University Graz, Institute for Hydraulics and Hydrology, p. 6.

Ritchie L., (2000). *A Literature Review And Data Analysis Of Benthic Macroinvertebrate Habitat Suitability For The Goquitlam River*, U.S. Department of Interior

Rozkošný R. (1980*). Klíč vodních larev hmyzu*, Československá Akademie věd

ACKNOWLEDGEMENTS

This work was supported by the project of Ministry of Education, Youth and Sport of Czech republic No MSM 211100002 and by the Czech Grant Agency project No.103/010675.