How to reduce the impact of combined sewer overflows on rivers having a natural weak flow?

Comment réduire l'impact des surverses de réseau unitaire sur les rivières à faible debit ?

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RÉSUMÉ

Le développement périurbain rapide conduit aux débordements incontrôlés d'égouts qui endommagent considérablement le fonctionnement écologique de petites rivières. Le projet ANR-EPEC (ANR-10-ECOTEC-007-01, 2012-2015) sur l'amélioration et la gestion de la capacité d'auto-épuration des eaux courantes a conduit à l'étude de solutions techniques qui pourraient aider les municipalités à contrebalancer l'effet néfaste de leur développement urbain rapide en adaptant la géomorphologie du lit de la rivière.

ABSTRACT

The rapid periurban development leads to uncontrolled combined sewer overflows that often dramatically damage the ecological functioning of small rivers. The project ANR-EPEC (ANR-10-ECOTEC-007-01, 2012-2015) on the enhancement and management of the self-purification capacity of running waters has led to the study of technical solutions that would help municipalities to counterbalance the detrimental effect of their rapid urban development using geomorphic adaptation of the river bed.

KEYWORDS

Combined sewer overflows (CSOs), pollution, stream, porous weir, self-purification

1 CONTEXT AND OBJECTIVES

The suburban development is characterized by a rapid development of impervious surfaces. These surfaces increase the runoff but the existing sewerage systems cannot convey all this water. To avoid the flooding of basements and urban roadways, combined sewer overflows units are set up on networks. Their function is to overflow the excess water (CSOs) towards a natural drainage system that is close enough to allow a gravity-transfer. These discharges are allowed 20 times a year in the European directive 91/271/EEC related to the waste-water systems management. The number of overflows is far exceeded in the context of a rapid urban development where the adaptation of the sanitation system takes time for reasons of cost and planning.

In this context, intermittent streams or streams with a low dilution capacity in comparison with the magnitude of sewer overflows (CSOs) are often degraded by an intense erosion process and by the organic pollution load they receive. A field experiment indicates that a technique used to reverse the erosion process can also contribute to reduce the pollution impact by developing its self-purification capacity (Wagner & Breil, 2013; Zhang et al, 2015). This point is explored in this work from a field experiment developed in the western periurban area of Lyon. It takes place on the Chaudanne creek which is part of the long-term monitoring sites of the OTHU project (http://www.graie.org/othu).

2 METHODS

The Chaudanne creek is a pluvial fed system flowing continuously from early November to late April at a mean discharge of 18 L/sec. It flows at 7 L/sec rest of the time with periods of no flows. Its catchment area is of 2.7 km2. The field experiment is organized around the first main CSO unit which impacts the creek. It receives on average 70 CSOs a year.

The reference station (0) is located upstream of the combined sewer overflow unit. It is a natural riffle, followed just downstream the CSO unit, by three artificial small weirs (stations 1, 2, 3) made of wooden trunks intertwined (Fig.1). That type of construction allows the water to seep through although it is not build for this purpose. The weirs were built in 2010 to stop the river bottom incision and the collapsing of river-banks resulting from the CSOs. The pools created upstream of these weirs have been rapidly filled by the sand carried during high flow events. The sand layer is lying on the granite bed-rock. Its depth is of 1m at stations 1 and 3 and of 0.2m at station 2. The last station (4) is a natural riffle like for the reference station 0. Riffles are known to be active metabolic points into rivers because they induce the water percolation (Namour et al., 2015).

Fig.1: (left) Location of sampling points in the Chaudanne River; (right) a picture of weir number 1.

During the low flow season it was observed that part of the polluted water coming from the CSOU was percolated in the sand accumulated behind the weirs. These structures finally work like filtration sand beds. But what is the fate of the organic pollution that goes inside? To answer this question, the quantification of selected pollution indicators like NH_4^+, NO_2^- , NO_3^- , DOC was performed at laboratory. Samples from surface and hyporheic waters were grabbed weekly from the field, from November 2, 2011 to October 9, 2012, resulting in hundreds of analyzes for each indicator.

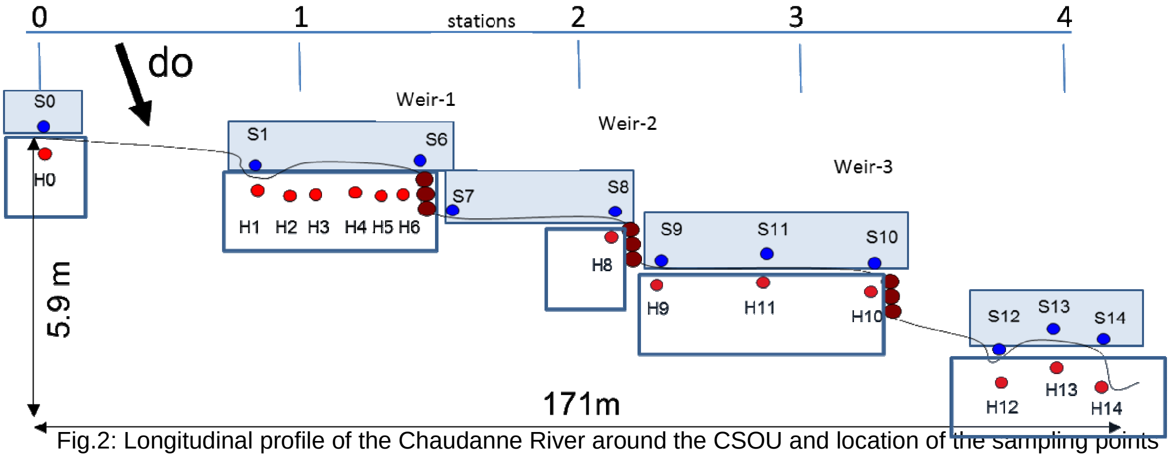

Fig.2: Longitudinal profile of the Chaudanne River around the CSOU and location of the sampling points

The S blue dots correspond to samples of surface water and the H red dots are for the hyporheic water samples. To perform the analysis of the effect of the weirs, data were grouped into stations (blue frames in Fig.2), but keeping separated the data from surface and hyporheic zones.

3 RESULTS AND DISCUSSION

The distributions of the corresponding concentrations of pollutants are shown in the form of box plot with interquartile 25% - 75%, and the median. The values beyond the quartile plus 1.5 times the interquartile distance are marked with a star symbol and external values to these limits (which are called outliers) by a circle symbol. Water quality is interpreted referring to the French legislation. The concentration data are interpreted using the graphs shown in Fig.3.

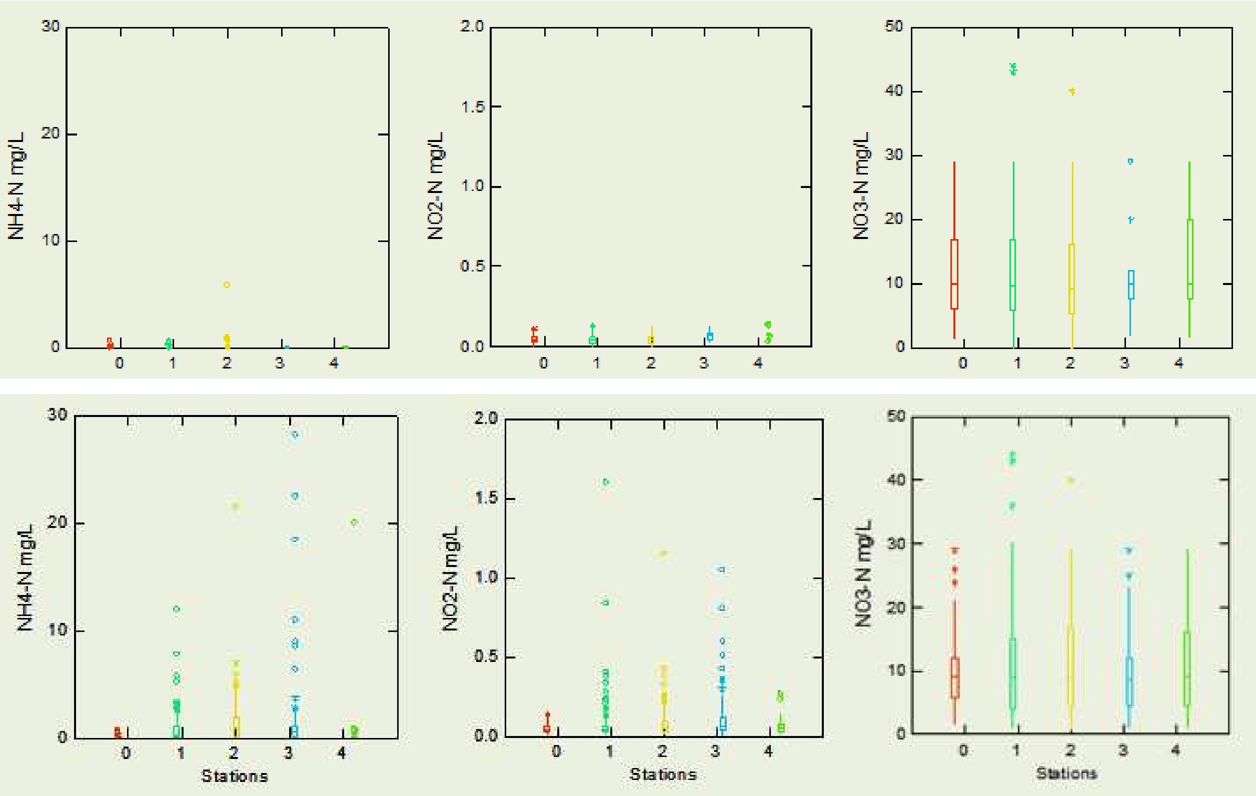

Fig.3 : Distribution of the nitrogen compounds in the surface (upper graph) and hyporheic (lower graph) waters.

3.1 NH_4^+

The ammonium concentrations in the surface water are most of the time less than 0.2 mg/L, which indicates a good quality overall. In details, there are 7 values from 0.2 to 1.2 and 1 at 6 mg/L. Considering the number of data these values are really exceptional.

In the hyporheic zone, concentrations are less than 2 mg/L at station 0, which is in agreement with surface water values at the same station and indicates again a good quality of the water in the sediment. The concentration is increasing from station 1 to station 3 and then decreases at station 4. A number of values greater than 3.9 mg/L are found at stations 1 to 3, which is far more that of the surface water at the same stations. This indicates a very bad water quality and shows that the anthropogenic pollution which is delivered by CSOs is efficiently trapped by the artificial sand beds created by the weirs. This is also confirmed by the fact that the ammonium concentrations at station 4 are similar to that of station 0.

3.2 NO_2^-

At the surface, nitrites concentrations never exceed 0.15 mg/L with a median value of 0.05, which means an acceptable water quality. In the hyporheic zone, concentrations remain less than 0.3 mg/L at stations 0 and 4. Values over this limit are met at station 1 to 3 and indicate a very bad water quality level. Nitrites come from the ammonium oxidation and are normally rapidly transformed into nitrates in the surface water. The observed large values at stations 1 to 3 can be explained by anaerobic conditions in the sand beds at certain periods.

3.3 NO_3^-

The nitrates concentrations show virtually no difference between surface and hyporheic waters and also between the five stations. They have all quite similar median values of around 10 mg/L which is considered of a bad water quality level. This indicates that the Chaudanne receives a lot of nitrates from its watershed area. This occurs in fact during the winter and spring seasons when fertilizers are spread over crop lands. Nitrates are drained from land to the Chaudanne creek by the runoff.

3.4 DOC and PO_4^{3-}

In the surface water, the dissolved organic matter (not figured here) exhibits a median concentration of around 10 mg/L at each station, and with (nearly) no zero values. This denotes a natural background of COD. A same pattern is observed for hyporheic waters at stations 0 and 4. However the concentrations can be over 12 mg/L at stations 1 to 3, which corresponds to a very bad quality of the water. It can be again invoked the trapping effect of the sand beds located just upstream the weirs. Same conclusions can be given for orthophosphates.

CONCLUSION AND PERSPECTIVES

The artificial porous weirs clearly act as a trap for the pollution which is delivered by CSOs. This is confirmed by the concentrations of NH_4^+, NO_2^-, PO_4^{3+} for which the ranges of variations are larger in the artificial weirs than in the natural riffles. The mean number of large concentration values (exceeding the upper quartile value calculated for surface water) is for the weirs of 36 in one year. As it is rare that the sampling of water has occurred during overflows, it is not possible to conclude that all pollution events have been trapped. However, the cumulative length of the 3 weirs, which is around 90m, creates opportunities for the interception of the carried pollution during low flow conditions. Conversely, natural high flows can favor the pollution dilution and a low impact on the ecosystem.It is noted that artificial weirs may also have low pollution levels at some times. These low values can be caused by a dilution effect which is induced by water that flows during the high flow periods caused by the catchment drainage. But they can also result from a bacterial self-purifying process. An oxidation gradient has been confirmed in the sand bed of station 1 (Breil et al., 2013). This oxidation gradient fades in periods of severe low water to make way for extensive reduction reactions with N2 and CH4 gaseous emissions.

As a perspective to this work, a dedicated metrology is required in the aim to well assess the dynamic of purifying process that occurs in the natural and artificial systems of a river (Namour et al., 2013). A device has been developed to measure gas releases at station 1 (Gervaix et al., 2015). First tests indicate that the gaseous flow was of the order of 1 liter per day and m2 during the low flow period.The EPEC project was also interested in how to increase the concentration of dissolved oxygen in the hyporheic water, in order to promote the oxidation reactions (Khdhiri et al., 2014). It is now possible to calculate the dimensions of a cascade in the aim to obtain a required percentage gain of dissolved oxygen. The waterfalls designed as ramps would have two advantages compared to a succession of artificial riffles like in the presented study: firstly, it would provide dissolved oxygen to the oxygen depleted waters outgoing from the artificial riffles, and secondly, it would maintain the hydraulic connectivity which is necessary for the movement of aquatic species.

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