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Impact of an intense combined sewer overflow event on the microbiological water quality of the Seine River

Julien Passerat [a], Nouho Koffi Ouattara [a], Jean-Marie Mouchel [b], Vincent Rocher [c], Pierre Servais [a,*]

[a] Ecologie des Systèmes Aquatiques, Université Libre de Bruxelles, Campus de la Plaine, CP 221, Boulevard du Triomphe, B-1050 Bruxelles, Belgium

[b] UMR 7619 Sisyphe, Université Pierre et Marie Curie, Case 105, 4 place Jussieu, 75005 Paris, France

[c] Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne, Direction du Développement et de la Prospective, 82 avenue Kléber, 92700 Colombes, France

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ABSTRACT

For a better understanding of the short and mid-term impacts of a combined sewer overflow (CSO) on the microbiological quality of the receiving river, we studied the composition of a CSO discharge and monitored during several hours the changes in the concentration of fecal indicator bacteria (FIB) in the impacted river water mass. The CSO occurred at the Clichy outfall (Paris agglomeration, France) in summer 2008 as a result of the most intense rainfall of the year. In 6h, 578, 705 m^3 of sewage and 124 t of suspended matter (SM) were discharged into the Seine River. The CSO contained 1.5×10^6 *E. coli* and 4.0×10^5 intestinal enterococci per 100 mL on average, and 77% of the *E. coli* were attached to SM. It was estimated that 89% of the CSO discharge was contributed by surface water runoff, and that resuspension of sewer sediment contributed to ~75% of the SM, 10–70% of the *E. coli* and 40–80% of the intestinal enterococci. Directly downstream from the CSO outfall, FIB concentrations in the impacted water mass of the Seine River (2.9×10^5 *E. coli* and 7.6×10^4 intestinal enterococci per 100 mL) exceeded by two orders of magnitude the usual dry weather concentrations. After 13–14 h of transit, these concentrations had decreased by 66% for *E. coli* and 79% for intestinal enterococci. This decline was well accounted for by our estimations of dilution, decay resulting from mortality or loss of culturability and sedimentation of the attached fraction of FIB.

1. Introduction

Many urban centers are drained by a unique sewer network in which wastewater is mixed with urban runoff water in wet weather. When rainfalls are intense, the transport capacity of the sewer system can be insufficient to allow all the water flow to reach the wastewater treatment plant (WWTP) or the treatment capacity of the WWTP can be insufficient to treat all the water flow. In such cases, combined sewer overflows (CSOs) occur, resulting in the discharge without any treatment of a mixture of wastewater and runoff water, loaded with urban surface pollution, into the receiving waters. CSO impacts on aquatic environments are multiple in terms of pollution types and dynamics in time and space, and encompass: (i) oxygen depletion due to the biodegradation of the high load of organic matter brought by the untreated wastewater, (ii) turbidity increase leading to the reduction of photosynthetic primary production, (iii) increase in the concentration of some

* *Corresponding author*. Tel.: +32 2 650 5995; fax: +32 2 650 5993.
E-mail address: pservais@ulb.ac.be (P. Servais).

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organic micro-pollutants, (iv) increase in metal concentrations and (v) increase in the concentration of pathogenic and fecal indicator micro-organisms.

Concerning this latter topic, a lot of studies have reported degraded microbiological water quality due to the release of stormwater runoff and CSO in various kinds of receiving natural waters as coastal zones (Hall et al., 1998; Noble et al., 2003), lakes (McLellan et al., 2007) and rivers (Rechenburg et al., 2006; Ham et al., 2009). Other researches were conducted on the microbiological quality of the CSO (Jefferies et al., 1990; Ashley and Dabrowski, 1995) but only few studies (Donovan et al., 2008) reported data on both microbiological CSO quality and its impact on the receiving water.

The aim of the present work was to study in parallel the fecal microbial contamination of a large CSO in the Parisian area and its impact on the Seine River. The Paris agglomeration is equipped with a combined sewer system and the Seine River is the receiving environment of the wastewater treated in WWTPs and of CSOs in wet weather conditions. This river is a typical example of an aquatic system severely impacted by wastewaters due to the large size of the conurbation (10 million inhabitants) and the relatively low discharge of the river (328 $m^3 s^{-1}$ on average at its entry into Paris). In the framework of the PIREN-Seine program (Meybeck et al., 1998), previous studies of CSO impacts on the Seine River had been mainly devoted to the problem of oxygen depletion. Anoxic conditions created in the river after CSO events used to cause fish mortality in the 90 s and before. Measurements were performed in CSOs (Seidl et al., 1998a; Servais et al., 1999) and downstream in the receiving Seine River (Seidl et al., 1998b) in order to improve the understanding of all the processes involved in oxygen depletion. This allowed the building of an ecological model, ProSe, able to describe and predict the impact of a CSO on the Seine River oxygen concentration (Even et al., 2004, 2007). CSO impacts on metal contamination were also investigated in the Parisian area (Estebe et al., 1998).

In the last ten years, the SIAAP (Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne), which is in charge of the management of the sewer network and the WWTPs in the Paris agglomeration, has developed significant efforts to reduce the frequency and the volume of the CSO spill events into the Seine River. Many facilities, allowing the storage or the treatment of wastewater during wet weather periods, have been built inside the sewer network (storage tunnels, detention basins) or in the WWTPs (ballasted flocculation processes). In addition, significant efforts have been made by the SIAAP operators to improve the control of the wastewater flow in the sewer system during wet weather periods, using hydrological and meteorological predictive models.

Despite this progress, CSO discharges still occur in the Parisian area and one of them was studied in August 2008. Up to now, no studies were devoted to the impact of CSOs on the microbiological water quality in the Parisian area. In the present study, we monitored the fecal microbial contamination discharged during an intense CSO occurring at the Clichy outfall, and we investigated the impacts on the microbiological quality of the receiving waters of the Seine River. The fecal indicator bacteria (FIB) *Escherichia coli* and intestinal enterococci were used to assess fecal contamination. FIB enumeration is commonly used to control microbiological water quality, as the search for the presence of all types of pathogens in aquatic systems is not feasible. Today, *E. coli* and intestinal enterococci are considered as the best FIB to predict the sanitary risk associated with freshwaters (Edberg et al., 2000; Kay et al., 2004).

2. Materials and methods

2.1. Study site

2.1.1. The combined sewer system of the Paris agglomeration and the Clichy CSO outfall

More than 75% of the sewage water from Paris and its suburb are collected and transported by gravitation towards three wastewater treatment plants (WWTPs) located in the western part of Paris agglomeration: Seine Centre (240,000 $m^3 d^{-1}$, hereafter referred as WWTP 1), Seine Aval 1,700,000 $m^3 d^{-1}$, WWTP 2) and Seine-Grésillons (1,00,000 $m^3 d^{-1}$, WWTP 3) (Fig. 1A). Treatment process at WWTP 1 and 3 consists of primary treatment, biofiltration for carbon and nitrogen removal and physico-chemical phosphorus removal. Treatment process at WWTP 2 consists of primary treatment, activated sludge for carbon removal, biofiltration for nitrogen removal and physico-chemical phosphorus removal. In their course, due to the presence of meanders, collectors leading to these WWTPs cross the Seine River by means of siphon systems. During rainstorm events their transport capacity may be exceeded and the water overload is discharged to the river.

A major wet weather outlet in this system is located on the right bank of the river, at the Clichy pretreatment plant. This plant is a major node in the sewer system: in dry weather conditions it collects and pre-treats (screening and grit removal) approximately 600,000 $m^3 d^{-1}$ of wastewater which are transferred towards the three WWTPs. WWTP 1 receives no other water except from the Clichy pretreatment plant, located 2 km upstream. Therefore, the quality of the influent water at WWTP 1 can be considered as well representative of the quality of the sewage water transiting at the Clichy site.

2.1.2. The Seine River

The Seine River has been canalized for more than a century and is nowadays equipped with navigation dams in order to maintain a constant water level between 4 and 5 m. Summer flow is regulated by reservoirs constructed on the upstream part of the Seine, Marne and Aube rivers. The average summer flow in Paris is 144 $m^3 s^{-1}$ (measured at the Austerlitz Bridge during the 1974–2009 period).

Positions in the Seine River are administratively identified by their kilometric point (KP), which is their distance in km from the reference bridge Pont Marie in downtown Paris. The Clichy CSO outfall is located at KP 23.4. Twice downstream from the Clichy outfall, the Seine River is divided into two arms by central longitudinal islands: first between KP 25.5 and KP 32.6 by the Île St-Denis, second between KP 40.3 and KP 50.6 by a continuous succession of islands beginning with the Île de Chatou and ending with the Île de la Loge (Fig. 1B). At KP 25.5, because the Clichy outfall is located on the right bank and the lateral dispersion is still limited, most of the water mass impacted by a Clichy CSO flows into the right arm. At KP 40.3, the impacted water mass flows into both arms, and we chose to