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ORGANIC CARBON BIODEGRADABILITY AND HETEROTROPHIC BACTERIA ALONG A COMBINED SEWER CATCHMENT DURING RAIN EVENTS

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ABSTRACT

The aim of this study was the evaluation of fluxes of organic carbon and biodegradability of waste waters during rain events in order to better predict the impacts of combined sewer overflows (CSO). The combined sewer system studied was located in a densely populated urban catchment adjacent to Paris. Five subcatchments of different size, have been monitored during several rain events for suspended solids, conductivity, ammonium, chemical and biological oxygen demand. In addition, two of these subcathments have been evaluated for dissolved and particulate organic carbon, their biodegradable fractions, and the total bacterial biomass. Several indexes, indicate a lower degradability of waste water during dry weather at the downstream stations, accompanied by an increase of bacterial size and bacterial biomass. A further decrease of biodegradable organic carbon related to rain intensity can be seen at all stations. Our results show a higher proportion of refractory organic carbon during rain events than during dry weather with a possible contribution of the in-sewer sediments to the bacterial wet weather flux. © 1998 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Bacteria; combined sewer; organic carbon; urban runoff; waste waters

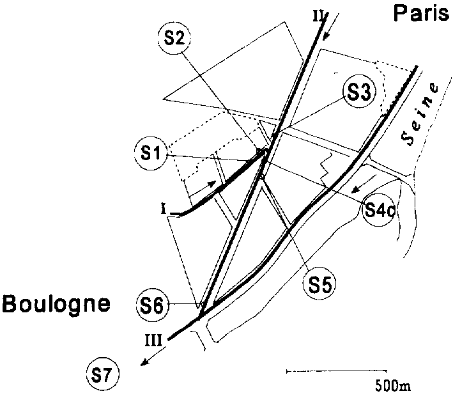
INTRODUCTION

The main impact of a CSO is generally a depletion of oxygen in the receiving waters due to an input of organic matter and bacteria. The degree of impact will be dependent on the sewer type, the rain intensity and the sewage characteristics as well as the properties of receiving waters (Harremoes, 1988). In order to understand better and model accurately the CSO impacts, it is essential to characterize all aspects of the wet weather discharge. In particular, special attention should be payed to the heterotrophic biomass and the biodegradable organic carbon, which may control the in situ degradation kinetics (Even *et al.*, 1996). In addition to complex solid transport patterns, the sewer acts as a biological reactor with bacterial growth and decay, substrate consumption and mineralization. The waste waters are depleted of oxygen as a result of aerobic degradation, rapidly replaced by facultative aerobiosis and anaerobiosis. Therefore one can expect that in addition to the organic matter, the heterotrophic populations will vary between dry and wet periods as well as with increasing residence time in the sewer system (Kaijun *et al.*, 1995).

The research program Piren-Seine brought out encouraging results regarding the characterization of biodegradable organic carbon of influents and effluents of the main waste water treatment plant of Paris, at Achères (Servais *et al.*, 1995). This paper reports a detailed study on bacteria and carbon speciation during wet weather, conducted on behalf of Water Authorities in a Paris suburb (Seidl *et al.*, 1996a) in association with an important flux study of SAFEGE Consulting Engineers (1996). Preliminary water quality data of a small subcatchment have been reported in Seidl *et al.* (1996b).

MATERIAL AND METHODS

The study area of the city of Boulogne, is situated on the right bank of the river Seine, adjacent to Paris. The sewer network is located upstream of the main WWTP Achères. The catchment is a densely populated urban area, drained by one main collector with a low slope. The sampling stations located at street level drained between 5 hectares for the smallest catchment upstream, and 395 hectares at the outlet of the Boulogne catchment (Figure 1). The study contained two parts: (i) A first campaign started at the end of 1994, designed to evaluate the degradability of organic matter, during dry weather period and 6 rain events, four of them at site S4c, just after mixing of S1 and S3, and two of them at site S6. (ii) A second campaign lasted until February 1996, for quantification of fluxes at all sites during a second dry weather period and a series of another six rain events. Sites S2 and S5 are the outlets of very small catchments and collect only urban runoff from the street surface. Site S7 is situated much further downstream and gathers most of the waste and runoff waters from the whole city of Boulogne.



Site	type	h (m)	(ha)
S1	collector	1.8	4.7
S2	surface runoff	-	0.28
S3	collector	2.3	28
S4c	collector	2.3	33
S5	surface runoff	-	0.19
S6	collector	2.3	43
S7	main trunk	2.7	395

Figure 1. Sketch of the catchment area of Boulogne-Billancourt. Collector height and catchment areas are given in the table.

During the first sampling campaign, special care was taken to keep the samples at 5°C during collection (PBMOS Buhler samplers) and transport. During a rain event, the sampling was activated by rise of the water level in the collector and 24 samples were taken in about 5 hours. For the second campaign, the sites were equipped with Calypso samplers working at the rate of 10 samples per hour for the duration of water level rise. The flow and the water level were measured by acoustic sensors with on-line control of the sampling threshold. Classical water quality parameters including conductivity, turbidity, suspended and volatile solids (SS and SVS), chemical oxygen demand (COD), NH_4, total Kjedahl nitrogen (TKN) and biological oxygen demand (BOD_5) were measured following the AFNOR (1986) or APHA (1989) standards. The separation between total and dissolved fractions was made by filtration under vacuum on glass fibre filters (Whatman GF/F or Schleicher & Schull equivalent). The measure of dissolved, particulate and total organic carbon (DOC, POC and TOC) and their biodegradable fractions, using a 40 days incubation period (BDOC, BPOC and BTOC) as well as the estimation of bacterial biomass by epifluorescence, were conducted as described by Servais *et al.* (1995). Several integrated samples from the first campaign were used for determination of degradation kinetics (Mouchel *et al.*, 1997). A summary of the samples taken for analysis is given in table 1. A rain event consists of 24 samples, which were equally mixed (for biodegradation experiments) or mixed proportionally to the flow (for flux evaluation) to give 6 or 8 subsamples.

Table 1. Number of samples taken during each event for the 2 campaigns of the Boulogne study.
* Conductivity was not measured for winter rain events

parameter	turbidity	conduct.	S.V.S	S.S.	COD total	COD soluble	BOD_5 total	BOD_5 soluble	Organic Carbon	biomass	TKN
1st campaign	24	24	-	6	24	-	6		6	6	-
2nd campaign	-	8*	8	8	8	8	8	8	-	-	8

RESULTS

Hydrology

During the dry weather periods we observed at all sites the usual hydraulic diurnal cycle (Figure 2). The daily flow maximum was slightly delayed with increasing surface area of the drained catchment. The hydraulic load decreased with increasing watershed and was about 70 $m^3/d/ha$ for S3 and S6, 25% higher for S1 and 40% lower for S7. A typical flow chart during a rain event is given for all sites in Figure 3. The propagation of the peak flow appears faster during wet weather than during dry weather.

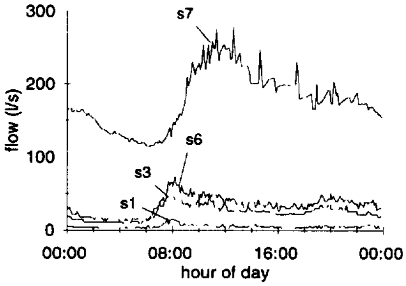


Figure 2. Hydro graphs for the 4 sites during dry weather (flow increases in order S1<S3<S6<S7).

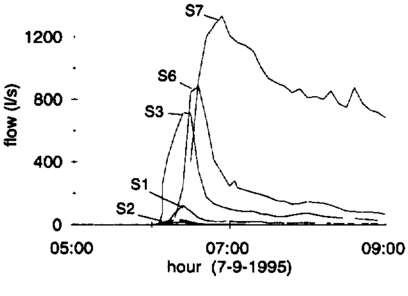


Figure 3. An example of hydro graphs for the rain event of 7th Sept. 1995, including street runoff. The total precipitation was 9.4 mm (flow increases in order S5<S2<S1<S3<S6<S7).

Because ammonium concentrations in urban runoff are usually very low compared to waste water concentrations, this cation can be used to estimate the proportion of rain and wastewater in collected samples. We decided to use NH_4 as a tracer of waste waters because of uncontrolled variations of chloride and conductivity data due to industrial activities and street de-icing. With regard to the important variations of ammonium concentrations during the day and night, special care was taken to select dry weather ammonium reference at the right hour of the day. Figure 4 shows that, during the event of 7th September 1995 (7-9-95), the smaller collector (S1) contained mainly runoff water, the larger collector at S3 contained different masses of rainwater, and further downstream at S7, only one mass of diluted water could be perceived.

The rain events of the first campaign, occurring during the day, modified only very slightly the sewer water quality because of (i) the short duration and low intensity of these events and (ii) the higher dry weather flow during the day. Rain events observed in the evening, or very early in the morning were longer, more intense and provoked a decrease of conductivity and turbidity. Figure 5 illustrates the evolution of turbidity at site S4c. A turbidity peak is observed at the beginning of all rain events, whereby for heavier rains (24-1-95 and 16-5-95) the turbidity may become even much lower than the corresponding dry weather value. 90% of all events collected during the second campaign at sites S1, S3 and S6 also showed a peak of suspended solids. A concentration of at least 450 mg-SS/l could be observed immediately at the start or just a few minutes after the activation of sampling, which means almost a doubling of the maximum daily dry weather concentration. These rapid fluctuations decrease along the sewer network (initial peaks observed at station S7 were lower) due to hydraulic damping inside the sewer and to the varying transit times of pollution peaks issued from different small sub-basins.

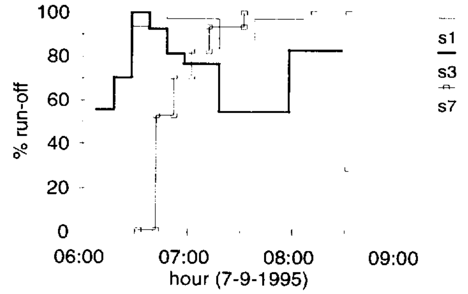


Figure 4. Variation of sewage composition in different collectors during the rain event 7-9-1995.

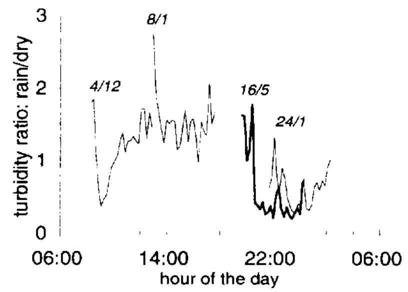


Figure 5. Evolution of turbidity during rain events, compared to the dry weather cycle. Results are given as a ratio of wet weather to dry weather (DW) concentrations.

Dry weather characteristics at different catchment scales

Daily mean, dry weather concentrations (Table 2) have been calculated as ratio of the total mass of pollutant to the total water volume. The concentrations are in the same range as found elsewhere in greater Paris

(Gromaire-Mertz *et al.*, 1998). The C/N ratios only refer to the organic matter. The first campaign allowed the determination of a significant regression between COD and TOC at sites S4c and S6, which was then used to compute TOC from the COD data obtained during the second campaign. Organic nitrogen was evaluated by difference between Kjeldahl nitrogen and ammonium nitrogen. We can observe a decrease of most parameters at station S7, which is most probably due to a dilution effect, but the increase of the C/N ratio at this station indicates a change in organic matter composition.

Table 2. Daily flows and flow mean concentrations for all sites during dry weather, average of data obtained in June and in October, ***b***: biodegradability calculated as BOD_5 /COD_t. The flow error is < 10%

site	flow m^3/day	S.S. mg/l	SVS mg/l	CODt mg-O_2/l	CODs mg-O_2/l	BOD_5 mg-O_2/l	NH_4 mg-N/l	Cl mg-/l	TKN mg-N/l	C/N	***b*** %
S1	441	194	159	442	161	216	35	67	59	5,5	49
S3	1988	146	116	348	122	135	27	72	43	6,6	39
S4c	-	186	-	396	115	152	-	-	-	-	38
S6	3142	236	195	447	165	217	23	64	45	6,1	49
S7	15408	140	107	251	65	112	19	68	28	8,6	45

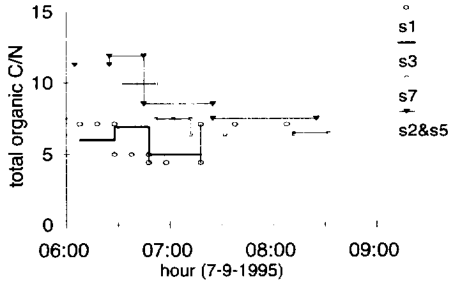


Figure 6. Evolution of organic C/N ratio during the rain event of 7th September, 1995. The dry weather average fall between 7 and 8 for all sites (not showed).

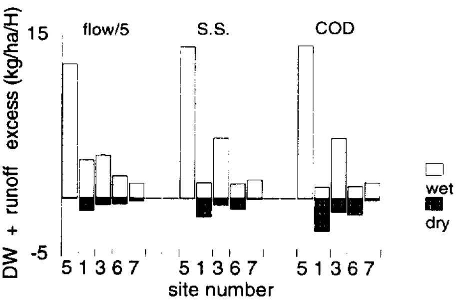


Figure 7. Comparison of dry weather fluxes (under the horizontal line) with excess wet weather fluxes (over the horizontal line) at all sites for the 7-9-95 event. The total transport during wet weather is equal to the sum of both bars. S.S. and COD_t are expressed in kg/ha/h, flows are expressed in m^3/ha/h but have been divided by 5 in order to fit.

Water quality and biodegradability during wet weather

Figure 6 demonstrates the fluctuation of the C/N ratio during the rain event of 7th September 1995. The initial C/N ratio of runoff material (sites S2 and S5) is very high compared to that of dry weather, due to the low concentration of total nitrogen in street deposits. By the end of the rain event, the C/N ratio of runoff water decreases simultaneously with that of its SS content, while the soluble COD remains almost constant.

It seems that the C/N ratio of dissolved matter in urban runoff is much lower than that of its SS. At sites S1 and S3, the C/N ratio is similar or only slightly higher than what was found during dry weather despite an increase of the COD and SS fluxes by a factor of four or more at site S3 (Figure 7). This would suggest that the source of excess organic matter flux does not originate principally from street runoff. At the site S7, the C/N ratios are higher, than what they were during dry weather. This is in contrast to site S3, where a contribution of an organic source is needed to explain the low C/N ratio.

A significant difference in biodegradation, calculated by the BOD_5 to COD ratio, can be observed between autochthonous and allochtonous organic matter. The ratio for street runoff varies from 10% to 15%, is much higher for all other sites (figure 8), but still lower than the dry weather ratio. As in the case of the C/N ratio, the strong flux increase during wet weather cannot be ascribed solely to street runoff which BOD_5 to COD ratio is much too low. It must be noted that despite a higher C/N ratio, organic matter at site S7 does not appear less degradable compared to upper sites as revealed by the BOD_5 over COD ratio.

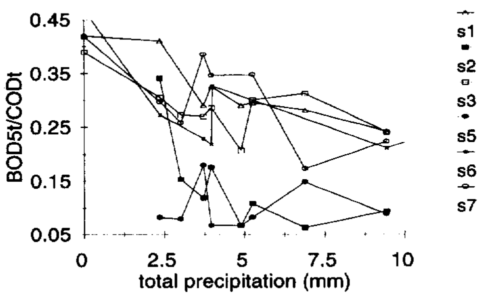


Figure 8. Biodegradability of organic matter during dry and wet weather, expressed as BOD_5 to COD ratio, as a function of the total precipitation.

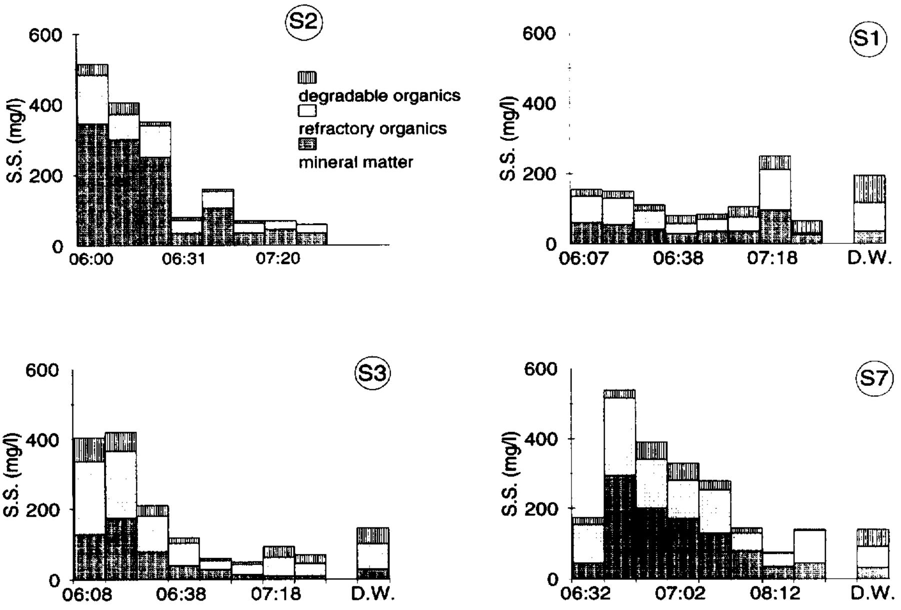


Figure 9. Characteristics of particulate matter collected at main sites during the rain event of 7th September 1995. A dry weather reference is given for the collectors S1, S3 and S7.

The data concerning solids alone (Figure 9), are in agreement with previous conclusions obtained for the total pollution. SVS data allow us to distinguish between the mineral and the organic fractions of suspended solids, while particulate COD and BOD_5 data (evaluated by difference between the total and the dissolved fraction) can be used to define operationally a degradable fraction of particulate organic matter within five days. The slight increase of mineral solids fraction during wet weather at sites S1 and S3 suggests that only a small amount of the less organic solids issued from street surface runoff can be mixed in SS loads observed at sites S1 and S3, which are not compatible with the large excess of SS flux. Indeed, the contribution of other sources of solids (runoff from roofs or yards as well as in sewer sediments) is required in order to explain the excess wet weather fluxes due to a pool of particles for which the characteristics are close to those of wet weather SS. At site S7 during wet weather, SS have a higher mineral content than they had at upstream sites S1 and S3.

Degradation kinetics experiments (Mouchel *et al.*, 1997) showed that the degradability of organic carbon was not the same at site S4c during dry weather and during a strong rain event (Figure 10). During wet weather, both DOC and POC are less degradable than during dry weather, roughly 65% of organic carbon was degradable during the strongest rain event (16th May 1995), contrary to 78% during the dry weather. However, when all rain events are considered, including events of lower intensity, the BTOC to TOC ratio of 74%, is no more significantly different between dry and wet weather. The five days biodegradability, computed as BOD_5 to COD ratio, decreased slightly during wet weather according to data obtained from the second campaign.

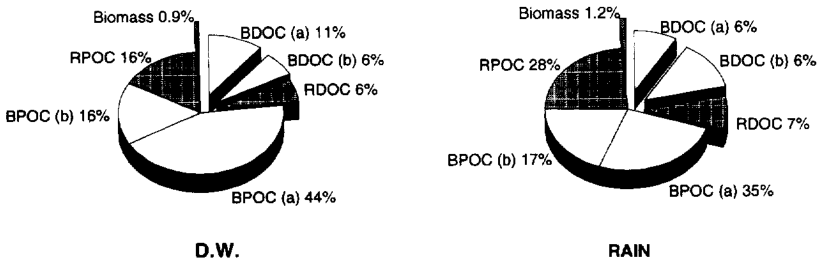


Figure 10. Mean composition of organic carbon at site S6/S4c during dry and wet period (16-5-95). BDOC (a): DOC biodegraded during the first 5 days of incubation, BDOC (b): DOC biodegraded between the 5th and 40th day of the incubation, RDOC: refractory DOC after 40 days. Same coding was used for POC.

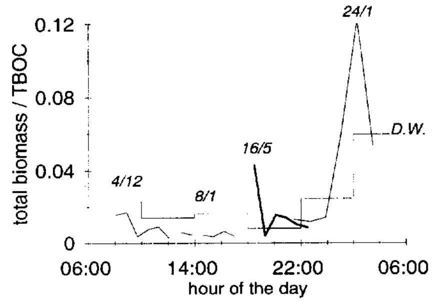


Figure 11. Evolution of total biomass (expressed as a fraction of BTOC) during rain events at S4c.

Bacterial biomass

Bacterial biomass is basically linked to BTOC, firstly because they have a common origin (waste waters or organic deposits) and secondly because high concentrations of degradable organic carbon favour the development of microbial biomass. To demonstrate the differences in bacterial development we present bacterial biomass data normalized to BTOC (Figure 11). A bacteria peak is observed for both heavy rains sampled at site S4c during the first campaign. During the 16th May event, the bacteria peak is coincident with the SS peak just at the beginning of sampling. During the 24th January event, the peak is no longer simultaneous with the SS peak, but still with the maximum flow. We argue that the source of bacterial biomass, with high biomass to BTOC ratio, which was activated during both strong rain events should be rather old, favouring BTOC decrease and bacterial biomass increase compared to dry weather waste waters. Since its contribution is more dependant on flow than on rain intensity we consider that the deposits and biofilms in sewers are more serious candidates than dry weather deposits on urban surface.

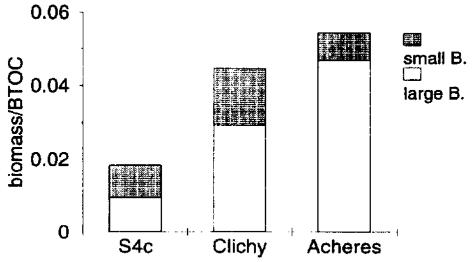


Figure 12. Evolution of bacterial composition along the sewer trunks in greater Paris. (S4c: Boulogne < Cl: Clichy < As: Achères).

The bacterial biomass measured at site S4c during dry weather represents 1.2% of BTOC and consists, calculated as carbon, of half small bacteria (<1μm) and half large bacteria (>1μm). The relationship between small and large bacteria is practically the same in all samples collected. The biomass of large bacteria is better correlated to particulate matter content, than that of small bacteria and particularly to BPOC than to the SS content. A part of these results differ significantly from data obtained downstream, at the outlet of the Paris sewer network, where the bacterial abundance was much higher (Servais *et al.*, 1994). If we compare the relative composition of the biomass during dry weather along the sewer network, we can observe a rise in the total biomass and in large bacteria (Figure 11). Bacterial growth (in size and biomass) is probably a function of residence time and abundance of appropriate substrate. The residence time of waste waters in the Clichy catchment is about 8 hours, whereby 4 more hours are needed to reach Achères.

CONCLUSIONS

Biodegradability of organic matter appears to decrease along the sewer system studied, as well as during the wet weather. Several biodegradability indexes have been used (organic C/N ratio, BOD_5/COD ratio, BTOC/TOC ratio and SVS/SS ratio). The C/N and SVS/SS ratios show a lower degradability of dry weather waste water and waste solids at the downstream station S7. C/N ratio, BOD_5/COD and SVS/SS ratios indicate that the degradability of waste water and waste solids decrease during wet weather in relation with the rain intensity. The BTOC/TOC ratio did not reveal such significant modifications during wet weather. The degradability of street runoff water and solids is much lower compared to dry weather waste waters. However flux estimations reveal that another pollution source with high degradability characteristics is necessary to explain water and SS characteristics observed during wet weather in this combined sewer network. This source could be in sewer deposits and biofilms.

Bacterial biomass and also bacteria size, increase inside the sewer network from upstream (Boulogne) to the downstream WWTP (Achères). This demonstrates the intensity of in sewer microbial processes and has to be related to the observed changes in degradability. During the stronger rain events, bacterial peaks can be observed, revealing the contribution of a pollution source with a high bacterial biomass to BTOC ratio. Here again, in sewer deposits and biofilms should be suspected.

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