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Résumé de l'article

Un suivi en continu du système d'assainissement de la Communauté d'Agglomération de Pau est mené depuis le mois de mars 2012 grâce à l'utilisation de pluviographes, de débitmètres, de turbidimètres et conductimètres. Des corrélations fiables ont été obtenues entre la turbidité, les matières en suspension (MES) et la demande chimique en oxygène (DCO) d'une part et entre la conductivité et l'azote total (TN) d'autre part. Ces mesures permettent une estimation instantanée et continue des flux de polluants transitant dans le réseau d'assainissement. L'article présente les résultats obtenus au mois d'octobre 2012 qui est caractérisé par une alternance de périodes de temps sec et d'événements pluvieux. Les données de turbidité et de conductivité montrent des tendances différentes pour un même type d'événement. Une augmentation de turbidité est observée au début de chaque épisode pluvieux, celle-ci variant en fonction de l'intensité des précipitations et de la durée de temps sec qui précède l'événement. À l'inverse, la conductivité diminue lors de chaque événement pluvieux en réponse à la dilution des eaux usées par l'eau de pluie. Le comportement différent de la DCO et de TN au cours d'un épisode pluvieux est dû à leurs répartitions différentes entre les phases dissoutes (TN) et particulaires (DCO). Les flux importants de DCO mesurés durant un événement de pluie précédé d'une longue période de temps sec mettent en évidence l'importance des phénomènes de sédimentation et d'érosion dans le réseau d'assainissement. Au cours de ces événements, les flux polluants rejetés vers le milieu récepteur peuvent être alors conséquents. Cela pose la question de leur impact sur la vie aquatique. Ces résultats montrent le potentiel de la mesure en continu pour une meilleure compréhension des systèmes d'assainissement. Cet outil pourrait être utile pour optimiser la gestion des eaux usées urbaines.

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CONTINUOUS MONITORING OF TURBIDITY AND CONDUCTIVITY IN WASTEWATER NETWORKS: AN EASY TOOL TO ASSESS THE POLLUTION LOAD DISCHARGED INTO RECEIVING WATER

Mesure en continu de la turbidité et de la conductivité dans le réseau d'assainissement : un outil simple pour suivre les charges de polluants déversées dans le milieu récepteur

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ABSTRACT

Continuous monitoring of the sanitation network of the urban catchment of Pau (southwest France) has been performed since March 2012 using rain gauges, flowmeters, as well as turbidity and conductivity probes. Good correlations were obtained between turbidity, total suspended solids (TSS) and chemical oxygen demand (COD) on the one hand, and conductivity and total nitrogen on the other hand. This allowed an instantaneous and continuous estimation of pollutant concentrations and fluxes since that date. In the present paper we focused on the results of October 2012, which was characterized by alternating periods of dry and rainy events. Turbidity and conductivity raw data show different trends during the study period depending on the parameter and the rain events. A turbidity peak is observed at the beginning of each rain event but its amplitude varies with the intensity of the rain and the length of the preceding dry

weather period. Conversely, conductivity decrease during each rain event implying, that rain water acts as a dilution factor. The behaviour of COD and total nitrogen differ markedly due to their partitioning between the dissolved (total nitrogen) and particulate phases (COD). Daily pollutant fluxes allow a global comprehension and monitoring of the sewer system. Important COD fluxes during a rain event preceded by a long dry weather period highlight the importance of erosion of sedimentary deposits in the sewerage network. During these events, important fluxes are discharged into receiving water leading to the question of the impact on aquatic life. Generally, these results highlight the potential of online monitoring to better understand the behaviour of the sewer network on long or short time scales. This could be a useful tool to manage wastewater treatment.

key words: Continuous monitoring, turbidity, conductivity, total suspended solids, chemical oxygen demand, total nitrogen, pollutant fluxes

RÉSUMÉ

Un suivi en continu du système d'assainissement de la Communauté d'Agglomération de Pau est mené depuis le mois de mars 2012 grâce à l'utilisation de pluviographes, de débitmètres, de turbidimètres et conductimètres. Des corrélations fiables ont été obtenues entre la turbidité, les matières en suspension (MES) et la demande chimique en oxygène (DCO) d'une part et entre la conductivité et l'azote total (TN) d'autre part. Ces mesures permettent une estimation instantanée et continue des flux de polluants transitant dans le réseau d'assainissement. L'article présente les résultats obtenus au mois d'octobre 2012 qui est caractérisé par une alternance de périodes de temps sec et d'événements pluvieux. Les données de turbidité et de conductivité montrent des tendances différentes pour un même type d'événement. Une augmentation de turbidité est observée au début de chaque épisode pluvieux, celle-ci variant en fonction de l'intensité des précipitations et de la durée de temps sec qui précède l'événement. À l'inverse, la conductivité diminue lors de chaque événement pluvieux en réponse à la dilution des eaux usées par l'eau de pluie. Le comportement différent de la DCO et de TN au cours d'un épisode pluvieux est dû à leurs répartitions différentes entre les phases dissoutes (TN) et particulaires (DCO). Les flux importants de DCO mesurés durant un événement de pluie précédé d'une longue période de temps sec mettent en évidence l'importance des phénomènes de sédimentation et d'érosion dans le réseau d'assainissement. Au cours de ces événements, les flux polluants rejetés vers le milieu récepteur peuvent être alors conséquents. Cela pose la question de leur impact sur la vie aquatique. Ces résultats montrent le potentiel de la mesure en continu pour une meilleure compréhension des systèmes d'assainissement. Cet outil pourrait être utile pour optimiser la gestion des eaux usées urbaines.

Mots clés : *Mesure en continu, turbidité, conductivité, matières en suspension, demande chimique en oxygène, azote total, flux polluants.*

1. INTRODUCTION

The European Water Framework Directive has targeted the aim of reaching "the good ecological and chemical status" for all of Europe's aquatic environments by 2015 WFD (2000). The impact of combined sewer overflows (CSO) on the quality of receiving environment has been widely demonstrated. CSOs collect both wastewaters and rainfall waters that may have high loads of anthropogenic pollutants (GROMAIRE *et al.*, 2001; CHEBBO and GROMAIRE, 2004; GASPERI *et al.*, 2008). In such a context, the reduction of the impact of wastewater effluents from CSO has become an important priority and

urban administrations have to take some measures to decrease the pollutant transfer towards the receiving environments. This challenge requires a perfect knowledge of the dynamic of the wastewater sewer system. Thus, determination of pollutant fluxes and loads is compulsory. Continuous monitoring of untreated wastewaters via CSO becomes a key issue for wastewater treatment management and protection of receiving environment. Monitoring based only on sample analyses being technically and economically unrealistic, it is necessary to turn to an indirect online determination of pollutant parameters. This can be done via the measurement of physical parameters such as turbidity as was recently demonstrated (JOANNIS *et al.*, 2010; LACOUR *et al.*, 2009; METADIER and BERTRAND-KRAJEWSKI, 2012). Turbidity online measurements allow the monitoring of global pollutant loads such as Total Suspended Solids (TSS) and Chemical Oxygen Demands (COD) (AUMOND and JOANNIS, 2006; LAWLER *et al.*, 2006). This further provides the dynamic of the studied systems with a higher resolution than analyses at laboratory scale. This could lead to a better management of CSO and wastewater treatment plant (WWTP) (BOUTAYATCH *et al.*, 2010; ROSIER *et al.*, 2010). Nevertheless, the use of online turbidity measurements to assess pollutant loads requires calibration, statistical work with continuous time series data to establish turbidity/TSS and turbidity/COD reliable relationships that must be established for each studied site.

In this study, we present the main results obtained for Pau urban sewer system monitoring (south-west France). Firstly, relationships between turbidity/TSS, turbidity/COD and for the first time conductivity/Total nitrogen as a function of different and representative rainfall events are demonstrated. The established correlations are thus used to assess continuous COD, TSS and total nitrogen load for October 2012 month.

2. MATERIALS AND METHODS

2.1 Study site

The combined sewer system of the urban area of the city of Pau (south-west France) drains about 50 km² with 150 000 inhabitants. The majority of the surface is composed of residential neighborhoods; several areas of commercial and industrial activities are also present. The ground impervious ratio is about 80%. The sewer network is 800 km long and more than 75% of the population is connected to a combined sewer. This study area covers the entirety of the catchment system as well as the sewer network, the CSO, the wastewater treatment plant and the receiving water (river "Gave de Pau"). That makes it possible to have a global comprehensive view of wastewater management from the sources until the discharge in the receiving environment.

2.2 Sensors and on line equipment

Since 2009, the study area is equipped with four tipping-bucket rain gauges, seven flow meters in the mains parts of the network and 27 CSOs have been also equipped with flow meters. For the monitoring of pollutant concentrations, one turbidimeter and one conductimeter were installed in March 2012 downstream from the junction of the two main pipes just before the WWTP. This site was chosen because it allows the monitoring, in the same time, of wastewater discharged at the main CSO of the study area and wastewater directed towards the WWTP. This probe is a nephelometric turbidimeter with a 0 to 4 000 NTU range. Turbidimeter is calibrated with formazine solution. The turbidity measurements can be disturbed by a waste in front of the probe; a technique for the removal of these outliers has been implemented. The conductivity probe is an inductive conductimeter with 0 to 10 000 $\mu\text{S}/\text{cm}$ range calibrated with NaCl solution. The two probes were previously calibrated at the laboratory and monthly *in situ* verification was performed. No derivation was observed during the entire course of the study period.

2.3 Sampling and analysis

For all samples, automatic samplers are used; the samples are systematically kept cold (4°C) and analyzed in the laboratory within 24 h following the protocols described below. All analysis are performed on the raw sample using the following methods. The measurement of turbidity and conductivity is made with the probes described above. Total Suspended Solids (TSS) are analyzed according to the NF T 90-105 standard. Chemical Oxygen Demand (COD) is determined with Aqualytic colorimetric kits after validation according to the normalized standard NF T 90-101. For total nitrogen measurements, a Shimadzu TOC-VCSN is used. For all these analysis, triplicates, standards and blanks are done.

2.4 Correlation functions

108 samples of wastewater were analyzed to establish the correlation between turbidity/TSS and COD. 70 samples were used for the correlation between total nitrogen and conductivity. The samples were taken from the entire network during dry and wet weather. Positive correlations between TSS/turbidity, COD/turbidity and total nitrogen/conductivity were found to be consistent (Figure 1). The corresponding correlation functions were established:

$$\text{TSS} = \text{Turbidity}^{1.0124} + e^{0.2894}$$

$$\text{COD} = \text{Turbidity}^{0.917} + e^{1.559}$$

$$\text{Total nitrogen} = \text{Conductivity}^{1.089} + e^{3.8501}$$

Correlation coefficients are between 0.83 and 0.92 and allow a good estimation of concentrations of pollutants. It has been demonstrated that these correlations are not statistically different between dry and wet weather. Indeed “a” and “b” coefficient are not statistically different for the dry and wet weather conditions for all of these correlations (in a 95% confidence interval).

3. RESULTS AND DISCUSSION

This section is devoted to the use of data recorded by all sensors during October 2012. This month was chosen because it is representative of the different weather situations that may be encountered in the study area with alternating periods of dry and wet weather and rainfall more or less intense. Firstly, the raw signal recordings of the sensors are presented. Then, the fluxes of pollutants are calculated daily and are presented and interpreted last. Before the use of data, the validity of linear correlation and validity of probes has been checked during all the duration of the study.

3.1 Temporal variability of the raw signal

Figure 2 gathers all the data recorded during October 2012. From the top to the lower part of the figure, rainfalls, treated flow at the WWTP, wastewater discharged at the CSO, conductivity and turbidity are showed. Data monitoring performed each five minutes allows a good understanding of the sewer system. This month starts with a period of ten days with dry weather. It shows that during this period, flow, turbidity and conductivity evolved in the same time. This is due to human and industrial activities. For these parameters, a minimum is observed during the night between 3:00 and 6:00 am. Then a maximum is observed around 11:00 am. Four periods of rain occurred during the month. For each one, although the treated flow goes up by a factor 2 compare to the dry weather period discharge by CSO occurred. During rain events, a turbidity peak is observed as soon as the flow goes up. Nevertheless, these peaks are different from one event to the other. It's particularly important for the first rain event (October 11 and 12, 2012) with a maximum around 450 NTU. But smaller for all the other events: between 150 and 250 NTU. Evolutions of conductivity during wet weather periods are really different from turbidity. For all the rain events, a decrease is observed and conductivity goes up at the end of the event. This decrease can reach a factor 7 compare to dry weather period and seems to be correlated with the flow increase. Using correlation functions presented before, these data can be converted in TSS, COD and total nitrogen concentrations and will be used to calculate pollutant fluxes.

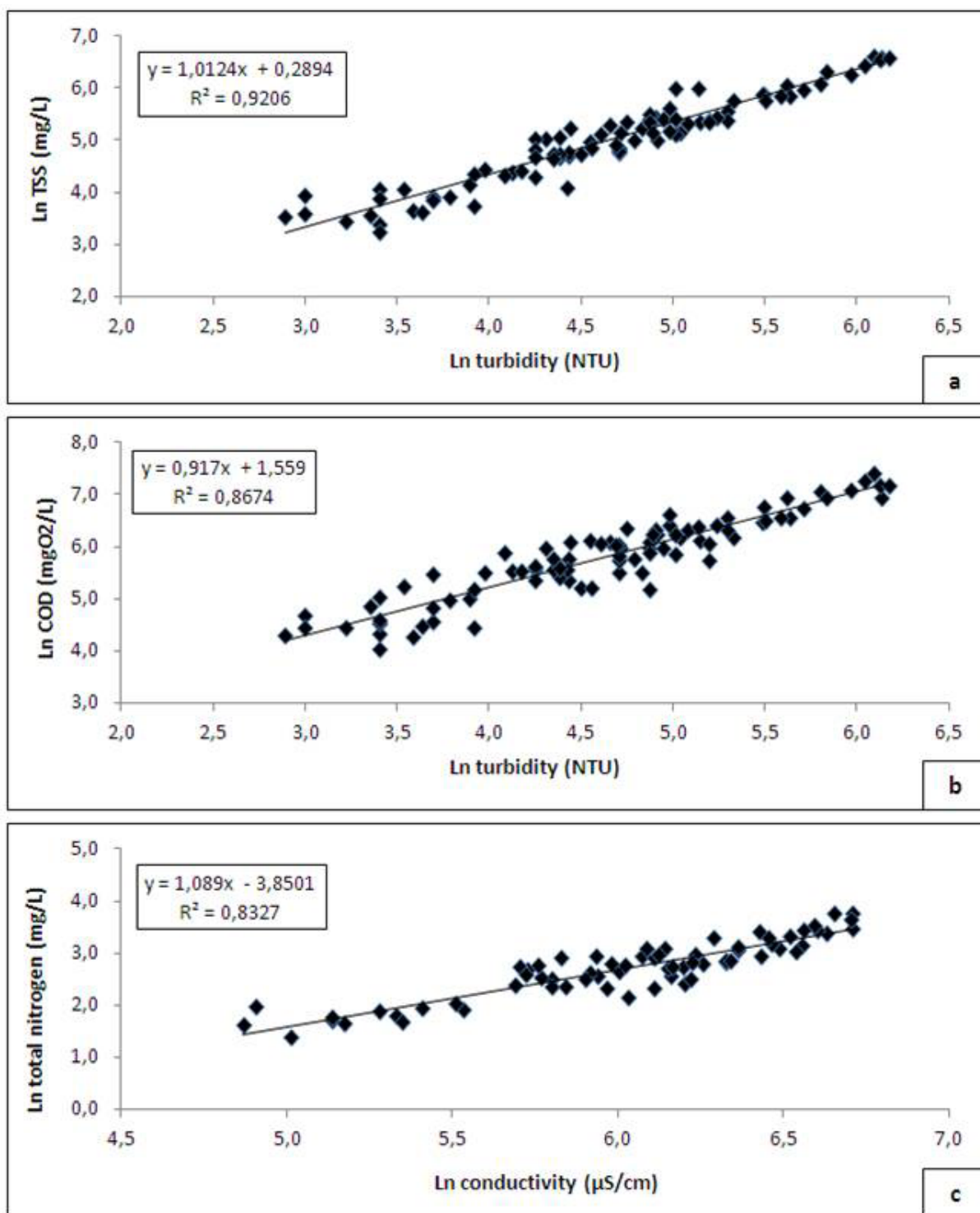


Figure 1. Relationships between a) \ln TSS / \ln turbidity b) \ln COD / \ln turbidity c) \ln total nitrogen / \ln conductivity
 Relations entre a) \ln MES / \ln turbidité b) \ln DCO / \ln turbidité c) \ln azote total / \ln conductivité

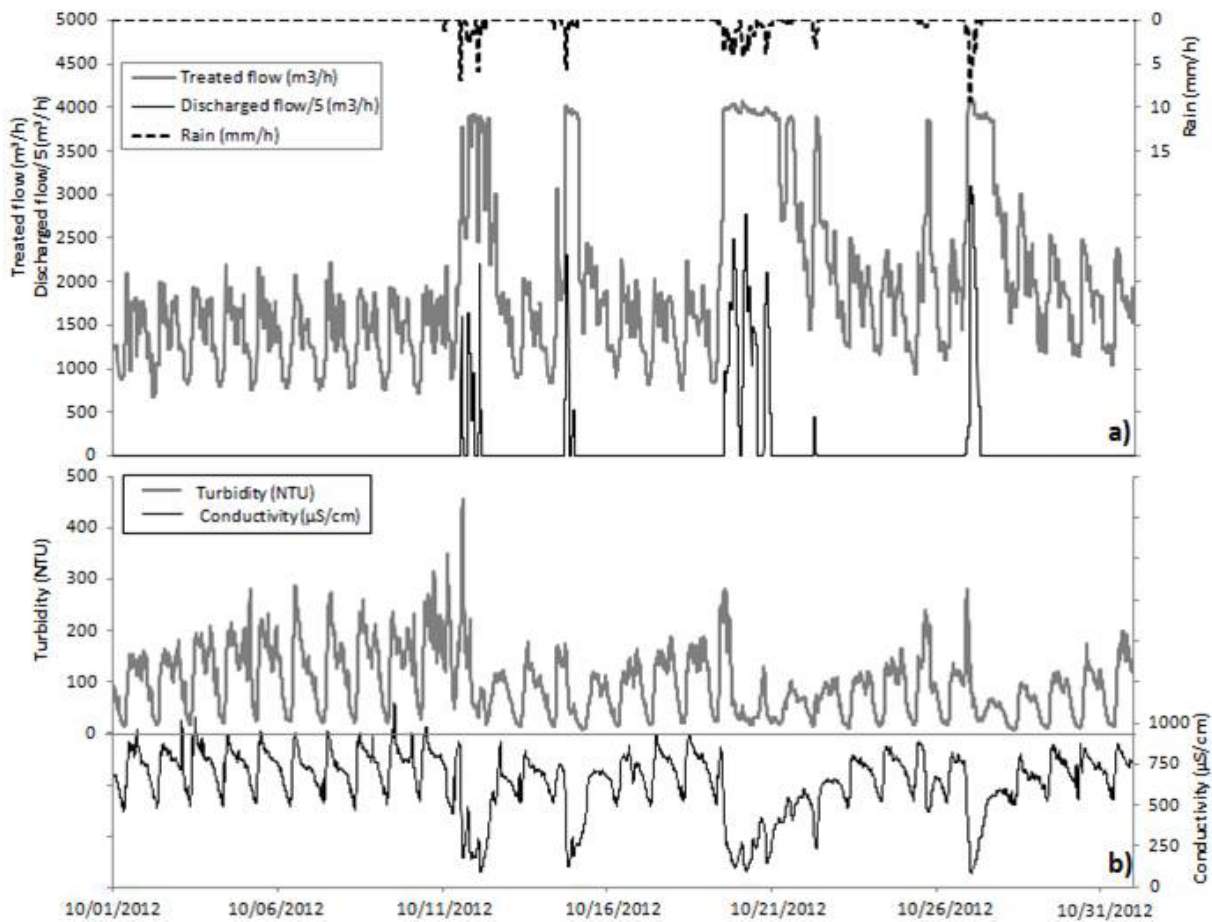


Figure 2. Overall presentation of continuous monitoring during the month of October 2012 a) rain, treated and discharged flows b) conductivity and turbidity
Présentation globale de la mesure en continu durant le mois d'octobre 2012 a) précipitations, débit traité et déversé b) conductivité et turbidité.

3.2 Daily fluxes of pollutants

To translate the large amount of data produced by the probes into comprehensive scheme of the network functioning over a long time period (a month or more), we integrated data at a daily scale by calculating daily fluxes of pollutants. **Figure 3** shows the results obtained for COD fluxes, flow and COD concentrations values. Because TSS and COD values result of the same measure (turbidity), they follow exactly the same trend, here just COD is presented. To make the discussion easier, characteristics of rain event of each day are presented in **table 1**. It is interesting to compare the three parameters studied: fluxes, flow and COD concentration. The first rainfall event that occurred on October 11, 2012 generates a COD fluxes increase by a factor 3.5 compare to the dry weather fluxes. This is due to the simultaneous increase of flow and COD concentration of respectively 2.7 and factor 1.3. During this event, stormwater contributes to increase the fluxes of pollutants probably in two ways, first by mobilizing pollutants on impermeable surfaces and secondly by sediment erosion

in the network. The latter is probably the predominant source for this increase. Indeed, this deposits resuspension phenomenon during rainfall events has been demonstrated in various studies (CHEBBO *et al.*, 2003; GROMAIRE *et al.*, 2006; HANNOUCHE *et al.*, 2011). The dry weather period particularly long (11 days) preceding this event is certainly the cause of the important increase in the fluxes due to a large stock of sediments rich in COD. The following rainfall events of 12 and 14 October 2012, although less intense, also generate a flow increase in the network of the same order of magnitude as that of October 11th. However, they differ in that the COD concentrations for these events are two times lower than during a dry spell. These events probably eroded less sediment, sediment stock erosion removed during the event of 11th have not been restored yet. Another phenomenon may contribute to the decrease in COD concentrations; it is the effect of dilution of wastewater by stormwater lightly loaded in COD. This dilution effect appears particularly marked during the subsequent events of 19 and 20 October. COD fluxes are 3.5 times greater the 19th than the 20th although the

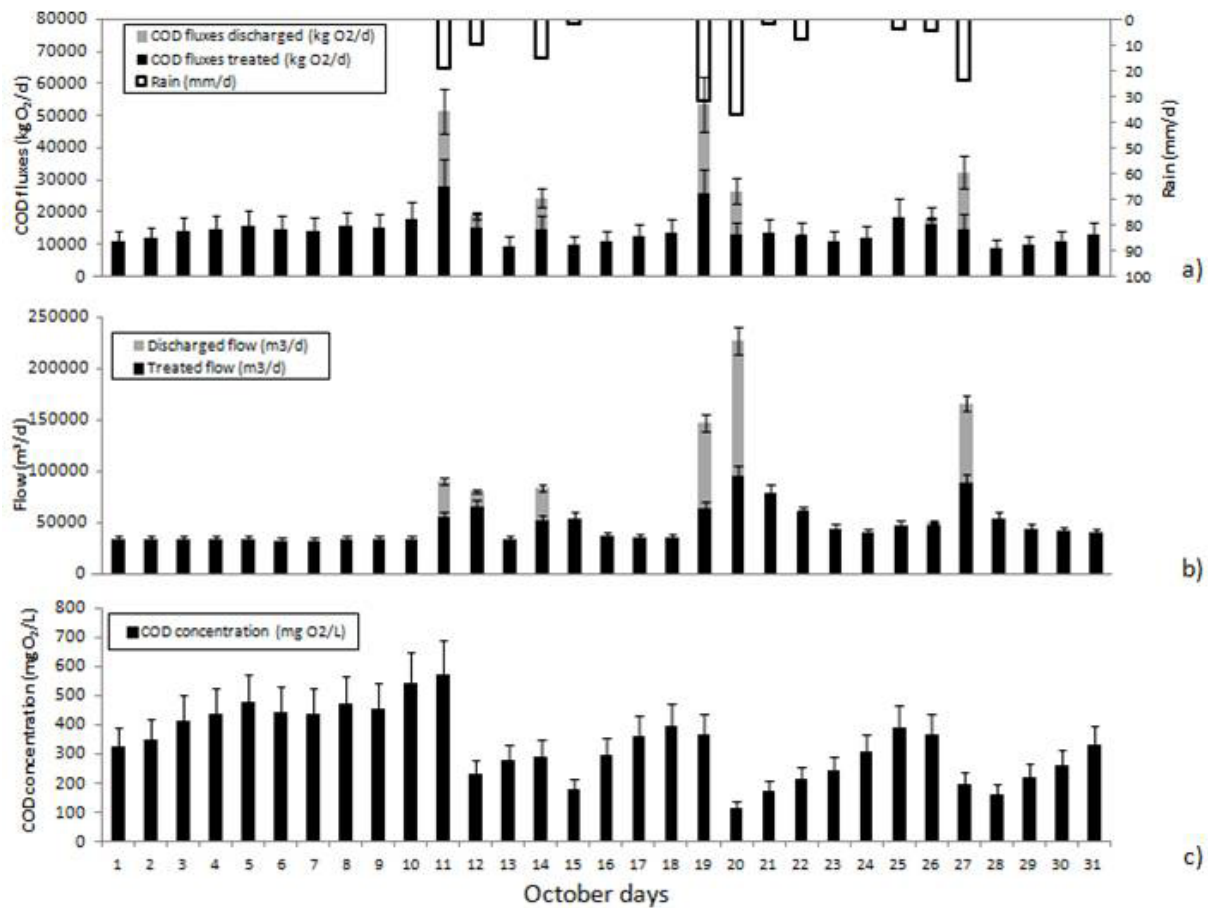


Figure 3. a) COD fluxes (kg/d) and rain (mm/d), (b) volume (m³/d) and (c) COD concentration (mg/L) during October 2012. (a) Flux de DCO (kg/j) et précipitations (mm/j), (b) volume (m³/j) et (c) concentration de DCO (mg/L) durant le mois d'octobre 2012.

Table 1. Characteristics of rainfall events occurring during the month of October 2012. *Tableau 1. Caractéristiques des événements pluvieux du mois d'octobre 2012.*

Date of rain event	Rainfall (mm)	Duration (h)	Average intensity (mm/h)	Maximum intensity (mm/h)	Antecedent dry weather period (d)
11	20.9	10	2.1	6.8	11
12	9.5	5	1.9	6.5	0
14	14.1	9	1.6	4.9	1
15	2.8	3	0.93	1.0	0
19	39.3	16	2.5	5.0	3
20	41.3	19	2.2	6.9	0
21	1.4	4	0.35	0.6	0
22	7.0	4	1.75	3.8	0
25	4.6	7	0.66	1.0	2
26	5.6	4	1.4	2.0	0
27	25.0	7	3.6	9.9	0

flows are higher the 20th (by a factor 1.5 with respect to 19). It is likely that the relatively low fluxes observed on the 20th are due to the fact that the sediments were eroded during the previous event and thus the amount of material available for this event is low. These examples highlight the complexity and the importance of erosion phenomena in wastewater and their importance in the transport of pollutants to the WWTP or the receiving environment. During this month, eight days of CSO (Combined Sewer Overflow) discharge were observed. The spilled volume varies between 130 000 and 2 000 m³/day in relation with the intensity and the depth of water precipitated. COD fluxes discharged into receiving waters vary in a wide range: from 400-28 000 kg O₂/d. The most critical events occurred on 11 and 19 October with a quantity of COD discharged close to 25 000 kg O₂ every day. However, spilled volumes are different on the two days with 35 500 and 83 000 m³ the 11th and 19th respectively. These data show the importance of not only considering the volume spilled but the flow of pollution in order to evaluate the impact on the receiving environment. Online measurement of pollutant concentrations is interesting because it allows to obtain, almost

instantaneous, information and thus makes possible a dynamic management of sanitation.

Figure 4 shows the total nitrogen fluxes, the rain, the total volume and the concentration of total nitrogen for the study period. Total nitrogen fluxes evolution is different to that observed for COD. Nitrogen fluxes vary relatively little over the period. During the largest rainfall event, they increase by a factor of 1.6 compared to dry weather fluxes. In dry weather, no significant difference could be observed. This behavior can be explained because in the sewerage, total nitrogen is mainly present in dissolved form (from 95 to 70%) (KAFI *et al.*, 2008). Therefore it is weakly influenced by the phenomena of deposits and sedimentation as it is the case for TSS and COD. Therefore, no significant phenomenon and resuspension during storm events accumulation is observed. Similarly, it seems that the contribution of runoff is low, nitrogen sources are mainly due to domestic and industrial inputs. According to KAFI-BENYAHIA (2006), the nitrogen due to runoff is consistently below 10%. The amount of nitrogen is slightly affected by rainfall events and remains essentially constant

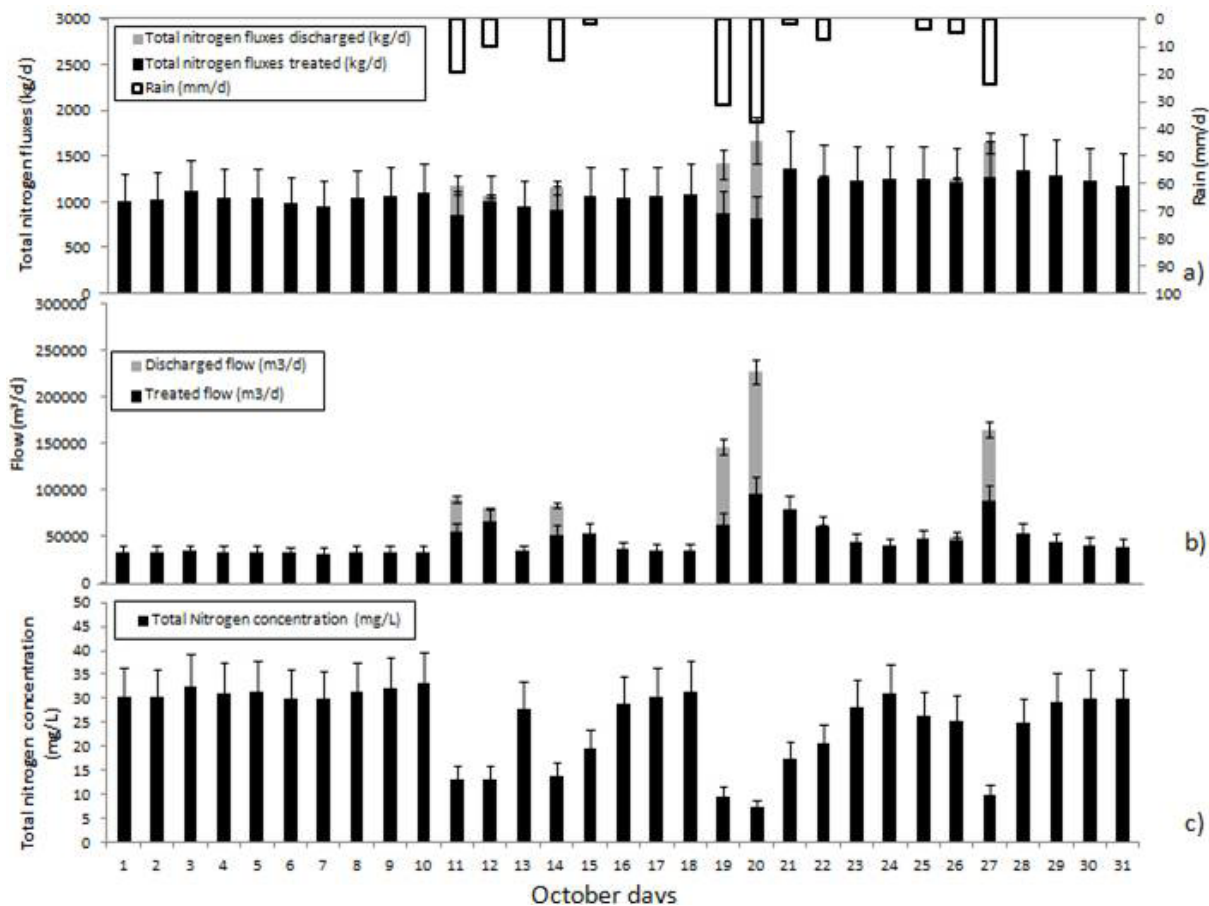


Figure 4. (a) Total nitrogen fluxes (kg/d) and rain (mm/d), (b) volume (m³/d) and (c) total nitrogen concentration (mg/L) during October 2012.
 (a) Flux d'azote total (kg/j) et précipitations (mm/j), (b) volume (m³/j) et (c) concentration d'azote total (mg/L) durant le mois d'octobre 2012.

during periods of dry weather and wet weather. During rainy periods, the flow increases at the same time a reduction of the total nitrogen concentration in proportion to the increase of flow was observed, and the fluxes are relatively steady. In the case of particularly significant rainfall events (that of October 20, for example), a small increase in fluxes is however observed (1.5 fold). According to GASPERI *et al.* (2010), in rain 30% of the nitrogen derived from resuspension of sediments and 6% of runoff which would explain the increase in flow. In contrast to what is observed for COD, following a rainfall event, nitrogen concentrations found their level of dry weather when the flow has recovered its level of dry weather which usually takes about three days.

CONCLUSION

Using turbidity and conductivity measurements to estimate continuous concentrations of pollutants in the sewage system of the CDAPP has been validated and is working for several months. This tool allowed making easier the monitoring of wastewater. It is possible to obtain an instantaneous and continuous estimation of the pollutant concentration which is very interesting for the sanitation manager. Then, this study examined different ways to process the data. The study of raw data allows a general monitoring and behavior of sewerage. However, from this information, pollutant fluxes can be calculated daily. This allows summarizing the information and to process large data sets (month, year) leading to a global monitoring that can take into account all situations (weather, activities, seasons) encountered in the study area. Moreover, this presentation allows an easy comparison between dry and wet periods, between different rain events or to the treated and discharge fluxes.

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