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Suivi expérimental hydrologique et énergétique d'un petit bassin versant urbain

Hydrologic and energetic experimental survey of a small urban watershed

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RESUME

Un suivi à long terme d'un petit bassin versant séparatif péri-urbain a démarré en janvier 2006 à Nantes (France) dans le cadre d'un réseau fédératif de recherche regroupant plusieurs laboratoires (IRSTV). L'objectif de cette étude est d'établir un bilan des flux d'eau, de polluants et d'énergie de ce bassin versant sur plusieurs années, pour contribuer à l'évaluation de modèles intégrés en milieu urbain, intégrant les compartiments sol et atmosphère. Les différents dispositifs expérimentaux mis en place sont présentés, et incluent un suivi en continu du débit et de la qualité à l'exutoire des deux réseaux d'assainissement, un suivi détaillé de paramètres météorologiques, ainsi qu'un suivi de la nappe. Les informations recueillies sur ce bassin pourront être mises à la disposition d'autres équipes et comparées à celles qui sont issues d'autres bassins versants expérimentaux. Les premiers résultats portent sur la pollution des eaux de ruissellement et montrent que les teneurs en micro-polluants sont faibles, à l'exception du zinc et de certains pesticides au printemps.

ABSTRACT

A long-term study of a small separative suburban watershed started in January 2006 in Nantes (France) in the frame of a federative research network (IRSTV). The objective of the study is to assess water, pollutant and energy balances for this watershed in order to issue integrated models including the soil and atmosphere compartments. The experimental devices are presented comprising a continuous monitoring of the flow and water quality at the outlet of the stormwater and wastewater networks, a detailed meteorological survey and a groundwater monitoring. The information collected on these watersheds will be available for other research teams and compared to the data obtained on other experimental watersheds. The first results show that stormwater metal concentrations are low, except for zinc which exceeds the standard for good quality surface water. Pesticide concentrations may also be high, depending on the season.

KEYWORDS

Fluxes ; micrometeorology ; pollution ; stormwater runoff ; waste water

1 CONTEXT AND OBJECTIVES

Stormwater runoff has been identified as one of the major causes of deterioration of the quality of receiving waters (Fam et al., 1987; Pitt et al., 1995; Smullen et al., 1999; Gromaire et al., 2001). The street solids and sewer deposited material are a source of pollutants in urban runoff (Lee et al., 2002; Gaspéri, 2006; Gaspéri et al., 2005). The management of urban stormwater evolves towards an integrated approach which requires an experimental and modelling research effort: design of innovative technologies, alternative strategies for rainwater management, treatment of urban wet-weather discharges and tools for analysis of drainage system operation...(Chocat et al., 2004).

In this context two experimental watersheds have been instrumented in France: OTHU and OPUR. The OTHU site located in Lyon started some 10 years ago with the objective to acquire a better knowledge and a better management of the water cycle in urban environments (Barraud et al., 2002; Bertrand-Krajewski et al., 2003). The OPUR site in Paris was launched in 1994 to improve the knowledge on sources, characteristics and transport mechanisms of micro-pollutants in a combined sewer. The first step of this project focused on pollution transport (Gromaire, 1998; Gonzalez, 2001), while the second step was devoted to the spatial evolution and the origin of the pollutants (Gaspéri, 2006). A third step has started in which suburban zones will be investigated.

More recently (January 2006) a new experimental urban catchment has been set up in Nantes (SAP) and a 4-year study started in the frame of a federative research network (IRSTV) supported by the Pays de la Loire Region. The objective of the study is to assess water, pollutant and energy balances for this watershed in order to issue integrated models including the soil and atmosphere compartments. This paper presents the implementation of the catchment together with the first results.

2 THE EXPERIMENTAL SITE

2.1.1 Hydrological characteristics

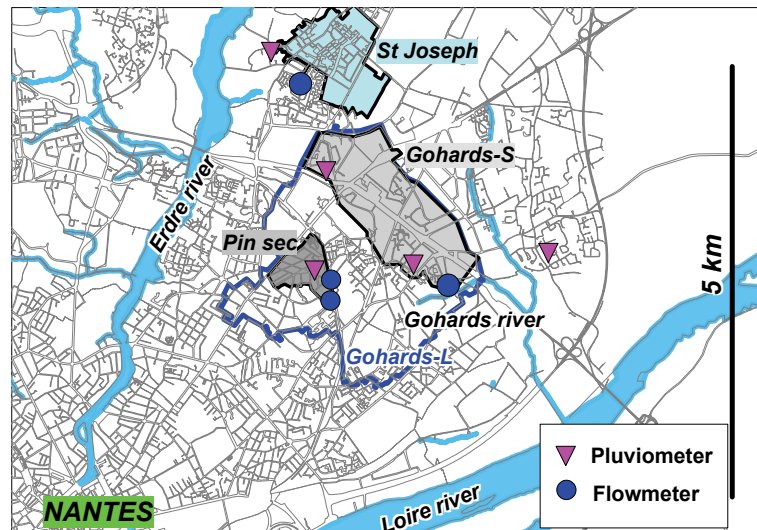


Figure 1. location of the study site in Nantes, France

In the frame of a regional project a large study site located in the East of Nantes (France), between the Loire and Erdre rivers (fig. 1) has been equipped for a long-term survey of water fluxes and soil-atmosphere exchanges. This zone includes a part of Nantes city, suburban zones some of which are currently being constructed, collective buildings, working areas. The instrumentation set up and the results presented here are devoted to the Pin Sec watershed (31 ha). A comparison with the other catchments of the study site will be done when these catchments are equipped. The Pin Sec habitat is mostly collective buildings. The impervious surface rate of the watershed is 45 % and the mean slope is about 1.1 %. The highest altitude of the catchment is about 28 m above sea level, and the lowest is 17 m. The catchment is equipped with a separative sewer network. The total length of the wastewater sewer system is 7.3 km whereas the total length of the rainwater sewer system is 4 km. The rainwater sewer system supplies a larger pipe draining into the Gohards river 1.2 km downstream. The wastewater sewer system is draining into a combined sewer system which is itself draining into the main sewer system of Nantes city, the outlet of which is the Tougas treatment plant, located 10 km downstream, along the Loire river. Rainfall is measured continuously by a tipping bucket rain gauge with a 1-min time step; the data are compared to those of 4 neighbouring rain gauges so as to detect and correct measurement errors and to estimate the spatial variability of the rain.

2.2 Flow measurement

The flowrate is observed both at the storm- and wastewater sewer outlets of the Pin sec watershed. The outlets are on circular pipes whose diameters are respectively 1.2 m for the stormwater pipe and 0.6 m for the waste water pipe. Preliminary investigations have shown that the water levels vary between 5 and 10 cm in the stormwater pipe during dry weather because of a small continuous flow.

One of the aims of the study is to assess the pollutant loads by means of a continuous monitoring with turbidimeters. However, these sensors require a minimum water height of 20 cm for the cells to be properly submerged without flow blockage. Thus it has been decided to install a weir but some questions remained about the influence of the weir on the velocity field. Larrarte et al. (2004) have shown that computational fluid dynamics (CFD) are an interesting tool to implement sensors in sewers.

The numerical procedure relies on the CFX software ability to solve 3D Navier-Stokes equations, and to predict velocity distributions over a cross-section. The equation system closure uses a Reynolds stress turbulence model (RSM). At the inlet, uniform velocity and water level are specified. At the outlet a pressure condition is imposed. The roughness of the solid walls has been evaluated to 2 mm. A volume of fluid method is used to represent the free surface. The numerical domain corresponds to a 1.2 m diameter circular pipe and a 20 cm high triangular weir is located into the pipe. The slope is 0.1%. Figure 2 shows the influence of the weir on the streamlines. It can be noticed that the velocity profiles are strongly influenced by the weir up to 3 m upstream. The profile remains stable between 3 and 5 m upstream of the weir. Thus the flowmeter has been implemented at 5 m.

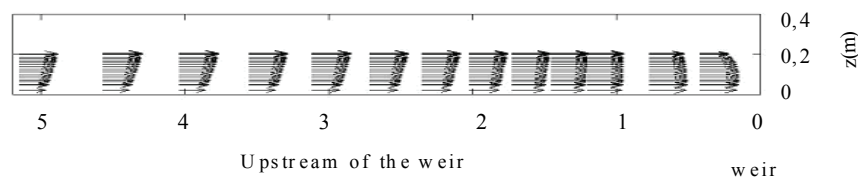


Figure 2. Influence of the weir on the stream line in the waste water collector

2.3 Sampling and analysis

An automatic sampler is set in the stormwater collector and both collectors are equipped for a continuous monitoring of turbidity. After each storm event water is collected from the sampler and stored at 4°C until analysis. Analyses are performed once a month on mean samples.

The analyses are carried out on raw samples and for metals on filtered samples (0.45 µm) to enable partitioning between particulate and soluble forms. Total organic carbon (TOC), pH and suspended solids (SS) are determined according to the French standards for sediment analysis (AFNOR, 1999). Determinations of metals are carried out by electrothermal atomic absorption spectrometry. An internal quality control solution is incorporated in each series. Total Kjeldahl nitrogen (NF EN 25663), polycyclic aromatic hydrocarbons (NF EN ISO 17993), total hydrocarbons (NF EN ISO 9377-2) and herbicides (NF EN ISO 11369) are also measured.

2.4 Groundwater monitoring

A continuous monitoring of the water table variations is possible thanks to 11 piezometers installed on and around the catchment (Fig.3). Pressure sensors located at the bottom of the wells allow a continuous observation of the water level with a time step of 20 minutes. The objective of this instrumentation consists in following the variations of the water table level due to meteorological forcing and to rain events. The spatial variability of the soil saturation level can be deduced from this set of data, and the main groundwater fluxes may be obtained. This kind of data is needed for the determination of a whole water quantitative balance on this specific zone. The groundwater characteristics of the soil are also measured, a special measurement site is equipped with water content sensors and tensiometers to estimate both soil moisture and hydric potential.



Figure 3. Instrumentation devices on the Pin sec watershed, delimited by the bold line

2.5 Microclimatology

The urban micro-climatology results from the interaction between urban morphology and regional climatology. The involved physical processes are the hydrologic and energetic transfers between urban surfaces and the atmosphere, at various scales, from the street to the agglomeration. The urban evapotranspiration term appears in the surface water budget and in the surface energy budget (in the form of the latent heat flux), supporting a strong coupling between the energetic and the hydrologic transfer processes at the urban surfaces (Berthier et al., 2006). Over the urban canopy the steady state energy budget can be written as:

$$R_n + Q_F = H_S + LE + Q^*$$

where R_n is the net all-wave radiation, H_S is the sensitive heat flux, LE is the latent heat flux, Q^* includes heat storage in the ground, materials, vegetation and canopy volume. The anthropogenic heat flux Q_F is due to the human activity: heating and air-conditioning of the buildings, industrial emissions, traffic,...

A weather station is set on a building roof to measure the local meteorological parameters: wind speed and direction, air temperature and humidity, atmospheric pressure, incoming solar and atmospheric radiations, and also diffuse solar radiation. In addition, a telescopic mast, 28 m in height, located next to the Pin Sec watershed, is equipped with sensors at several levels in order to obtain the profiles of temperature and humidity, to measure the wind speed and direction, and the turbulent fluxes. These fluxes are evaluated using the eddy-correlation method with a sonic anemometer (Metek, USA-1) and a CO_2/H_2O gas analyzer (LI-COR 7500, open path) at the higher level (26 m agl); another sonic anemometer also provides the sensible heat flux at a lower level (18 m agl).

The area surrounding the site of the mast is heterogeneous, representative of the SAP site. So, by implementing footprint models, relations between the measurement height and the extent of the representative urban zone will be established according to the meteorological conditions. In the energy budget, the radiative component will then be more correctly evaluated according to:

$$R_n = (1-a) K_{\downarrow} + \varepsilon L_{\downarrow} - \varepsilon \sigma T^4$$

where K_{\downarrow} and L_{\downarrow} , the incoming solar and IR radiations, are measured at the roof top (weather station, Pin Sec), σ is the Stefan-Boltzmann constant, a , ε and T are respectively the effective albedo, infrared emissivity and surface temperature of the zones which contribute to the turbulent flows measured on the mast.

2.6.1 Data management

All measured data (recordings from loggers, instant readings by operators, results of laboratory analysis) are imported on a monthly basis in a single data base, which has been built by the means of a readily available software package called "Minautor". This software has been originally developed by the Loire Bretagne Water Authority in collaboration with LCPC for managing and analysing data from SCADA systems on sewer networks. This package could be called an "historical information system (HIS)" as it has been designed for an efficient management of measured time series and associated events like calibration and maintenance operations. It relies upon a database structure implemented in Oracle™ server database management system, completed by a set of dedicated tools. It can handle a variety of measured quantities and sampling strategies, and includes features like re-sampling, management of measuring units, affectation of quality codes, detection of missing data, correction of a

drifting sensor, and simple hydraulic and hydrological calculations. The database also includes a rough and global description of each watershed (total area, surface area, population, etc.) and of the upstream-downstream relationships between them. In the future, a specific database, including both detailed geographic features and historical recordings will be developed as a research project.

3. RESULTS

The first results shown here concern stormwater quality.

Mean pollutant concentrations in wet-weather, dry-weather and rain waters are reported in Table 1 together with drinking water and surface water standards (SEQ-EAU, eau verte, meaning good quality water) defined by French Water Authorities. All pH values are in the range of 6.3 to 7.2 with a mean value of 6.8 close to neutrality. Mean suspended solid concentration is 116 mg L^{-1} with a high dispersion. This value is well above the standards for surface water and drinking water production. Suspended solids are the highest in June (366 mg L^{-1}) probably due to a wastewater intrusion in the stormwater network (TKN, TP and TOC are also abnormally high), while the lowest value is 34 mg L^{-1} in April. Note that the mean value drops to 66 mg L^{-1} if the suspicious June value is not taken into account.

Mean Cd concentration is very low ($0.2 \text{ } \mu\text{g L}^{-1}$ below the standards for surface and drinking waters. Most of Cd (80 %) is in the particulate form. Chromium and Ni concentrations are also low, with mean values of $3 \text{ } \mu\text{g L}^{-1}$ for Cr and $6 \text{ } \mu\text{g L}^{-1}$ for Ni. These metals are mainly dissolved (67 % for Cr, 74 % for Ni). Copper concentration is $28 \text{ } \mu\text{g L}^{-1}$ on average, ranging from 9 to $53 \text{ } \mu\text{g L}^{-1}$. The mean value is close to the standards for surface water (Tab. 1). Copper is mainly in the particulate form (65 %), which is in agreement with the results of Gromaire et al. (2001). Ninety percent of lead is particulate Pb in agreement with other studies. The mean concentration is $30 \text{ } \mu\text{g L}^{-1}$ a little above the standards. This concentration is lower than those generally reported due to the decrease in the use of leaded gasoline. Zinc concentration is $336 \text{ } \mu\text{g L}^{-1}$, well above the standard for surface water. Eighty percent of Zn is in the particulate form; Gromaire et al. (2001) also found that most of Zn is particulate Zn in the case of an urban watershed. Metal concentrations are generally comparable to those reported by Legret and Pagotto (1998) and Pagotto et al. (2000) for highway runoff waters and by Ruban et al. (2005) for a neighbouring watershed.

Contrary to metals, very high concentrations of pesticides, especially glyphosate (up to $37 \text{ } \mu\text{g L}^{-1}$ in June) have been measured; this herbicide is commonly used by gardeners and municipalities which could explain the concentrations in this suburban zone. Hydrocarbons and PAHs concentrations are low.

It has to be noted that these storm-water runoff concentrations, though generally low are, however, much higher than rainfall concentrations measured on the same site (Tab. 1). This suggests that in the present study pollutants in storm-water runoff mainly come from the street wash off with a minor contribution from atmospheric deposition.

	Rain water	Wet-weather	Dry-weather	Decree 2001-1220*	Surface water** SEQ EAU -eau verte
SS mg L ⁻¹	< 1	116	5	25	25
TOC mg L ⁻¹	< 0.1	31	3.9	30	30
TKN mg L ⁻¹	< 1	1.9	2.3	1-3	2
pH	5.7	6.8	6.6	5.5-9.0	6.0-8.5
TP	-	0.41	0.34		
Cd µg L ⁻¹	< 0.1	0.2	< 0.1	5	0.85
Cr µg L ⁻¹	1.8	3	1.8	50	36
Cu µg L ⁻¹	2	28	5	50-1000	27
Ni µg L ⁻¹	1.8	6	9.5	-	20
Pb µg L ⁻¹	< 1	30	8	25	23
Zn µg L ⁻¹	< 10	336	10	3000-5000	140
Tot. pesticides µg L ⁻¹	< 0.01	30	0.09	0.5-5	-
Total HC mg L ⁻¹	< 0.1	53	< 0.1	50-1000	-
Total PAHs µg L ⁻¹	< 0.01	0.14	0.03	0.2-1	0.20

Table 1 : Pin Sec catchment - comparison of mean pollutant concentrations in wet-weather, dry-weather and rain waters for the period April 2006-September 2006. SS: suspended solids, TOC: total organic carbon, TKN: total Kjeldhal nitrogen, TP: total phosphorus, HC: hydrocarbons.
*Decree of 20 December 2001 on surface water used for drinking water production. **French standard for surface water of good quality

4. CONCLUSION

A long term study of a small separate watershed started in January 2006 in Nantes (France) in the frame of a federative research network (IRSTV). Flowmeters and turbidimeters are installed in the stormwater and wastewater collectors for a continuous monitoring. The information collected on these watersheds will be available for other research teams and compared to the data obtained on other experimental watersheds, they will also be useful to water managers for a better management of water in urban environments.

The first results show that micro-pollutant concentrations in stormwater are generally below the standards for surface water of good quality. However, Zn concentrations are above this standard, so as pesticides (glyphosate) in spring.

In the coming months the Gohard stream will be equipped for flow and water quality monitoring increasing the information collected on the SAP. Besides a confrontation of the data regarding the different watersheds of the SAP i.e. St Joseph and Gohards catchments (Fig. 1) will be made. A detailed characterization of the land use by means of remote sensing methods (hyperspectral imaging) is also scheduled on the SAP.

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