

Quality of stormwater runoff from paved surfaces of two production sites

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Abstract In order to investigate stormwater pollutant loads associated with different anthropic activities and the related pollutant build-up and wash-off processes, two pilot sites have been equipped in the Liguria Region (Italy) for monitoring first flush water quality in a gas station and an auto dismantler facility. TSS, COD, HC_{tot} and heavy metals in dissolved form (Zn, Pb, Cu, Ni, Cd, Cr) have been analyzed during the monitoring campaign (started in February 2004). Stormwater flow and quality data collected in both production sites confirm that EMC values are significantly higher than those observed in an urban site. In the auto dismantler site, the EMC values for TSS, COD and HC largely exceed the standard values (EC 91/271). Contrary to urban surface runoff, scarce correlation between TSS and COD concentrations is observed in runoff from both production sites. The occurrence and nature of the pollutant load connected to first flush flows is discussed by inspection of the $M(V)$ -curves that are provided for all monitored water quality parameters. Significant first flush phenomenon is evidenced for TSS and HC, while such clear behavior doesn't emerge for heavy metals. Hydrologic and climatic characteristics (ADWP, rainfall intensity/depth) appear to scarcely affect the build-up and wash-off processes.

Keywords First flush; production sites; stormwater; urban drainage

Introduction

In order to achieve the stormwater runoff management objectives set forth by the European guidelines, the design criteria of cost-effective storage/treatment devices should be tackled.

For this purpose a better understanding of the pollutant build-up and wash-off processes from different paved surfaces is required. Several studies demonstrated the site-specific features of such processes, focusing mainly on non point-pollution sources constituted by urban surfaces such as roads, roofs, parking lots etc. (Spångberg and Niemczynowicz, 1993; Tomanovic and Makcimovic, 1996; Brockbank *et al.*, 1999; Ball *et al.*, 2000; He *et al.*, 2001). In these cases the occurrence of the first flush phenomenon has been shown, thus identifying the first part of the storm runoff as the most polluted. Various definitions of the phenomenon were proposed as a function of the results of dedicated monitoring campaigns which allowed to identify the most relevant factors affecting the first flush (Saget *et al.*, 1995; Gupta and Saul, 1996; Deletic, 1998; Bertrand-Krajewski *et al.*, 1998). At present, due to the lack of an universal definition of the first flush phenomenon, design criteria and regulations for storm runoff management devices are based on the determination of the runoff volume to be collected and treated per unit impervious area; such criteria are seldom supported by specific experimental data.

Less frequent are cases where the point pollution sources in urban areas – e.g. the external areas of production sites – are investigated. Production sites generally have heterogeneous characteristics and the associated pollutant load is strongly related to the specific activities, although it is always possible to group them into categories with homogeneous expected pollutants load. Some of these categories (such as gas stations)

are characterized by limited external areas but at the same time they are numerous and spread on the urbanized area. The harbor areas are another significant point source of pollutants in coastal regions. This kind of production site plays a significant role in terms of pollutant load discharged into the receiving water body: they are in fact, characterized by large impervious surfaces where tourist-commercial activities are carried on.

Starting in 2002 the Department of Environmental Engineering of the University of Genoa is carrying out a monitoring project on storm water runoff quality from different paved surfaces among urban areas, production sites and harbour areas (the latter is actually in the start-up phase). The aim is to assess the associated pollution load and to investigate pollutant production and transport processes into the drainage system. In this paper the results of the monitoring campaign regarding two different categories of production sites (still in progress) are presented and compared to the results already obtained in residential areas.

The monitoring project is carried on in collaboration with the local authorities (the Liguria Region and Province of Genoa) in charge of stormwater runoff regulation and control. The typologies of production site under investigation have been chosen based on the expected pollutant load and their number and distribution on the territory.

Data collection and results

Experimental site and equipment

The quality of stormwater runoff associated with the paved external surface of a gas station and an auto recycler and dismantler facility has been investigated. Each station is basically equipped with an automatic sampler (12 glass bottles with 0.95 l capacity) for water quality aspects and with a system for continuous flow monitoring designed according to the specific site characteristics. Both production sites are also equipped with a tipping bucket raingauge (20 gr. bucket capacity).

The gas station is located on the highway A12 Genoa – Livorno; it is constituted of refuelling stations, a parking lot for trucks and buses and a motorway restaurant. The monitored area has an extension of about 5000 m², totally paved; the drainage system covers the entire area and conveys stormwater runoff into a simple treatment plant (settling and oil separation tanks). The sampling station has been installed in the final manhole before water enters the treatment plant.

The auto recycler and dismantler facility is located in Chiavari nearby Genoa. It covers an area of about 6500 m² out of which 700 m² are covered by an industrial building used for vehicles dismantler activities, while the rest of the site consists of an open area, totally paved, used for the storage of scrapped vehicles and various metallic materials. The drainage system conveys stormwater runoff in two first flush tanks. The study area of concern is about 4500 m² and the sampling station is installed inside the first sedimentation chamber of one of the first flush tanks.

Collected data set

In both sampling stations the following data are collected for each rain event: five minutes rainfall data, one-minute runoff data obtained from continuous level measurement and runoff samples automatically collected at five minute intervals. As for water quality, laboratory analyses of runoff samples are performed on the following chemical-physical parameters: total suspended solids (TSS), chemical oxygen demand (COD), total and linear aliphatic Hydrocarbons (HC_{tot}) and heavy metals in dissolved form (Zn, Pb, Cu). Due to the specific activity, additional detailed investigation was carried out in the auto dismantler facility site by analyzing cadmium (Cd), chromium (Cr) and nickel (Ni) in dissolved form.

At the auto dismantler facility, 15 rainfall events have been monitored; in particular for 11 events laboratory tests of water samples were performed. At the gas station site water quality and flow measurement data from 5 rainfall events are available.

The limited data set collected in the latter site is due to treatment plant pumps breakdown which caused back-flow phenomenon in the drainage system. Such problems determined unsuitable conditions for flow measurements and water quality monitoring.

At the auto dismantler site, are summarized in [Table 1](#) the main characteristics of the monitored rain events. It can be noted that such events, collected from February to December, are mainly characterized by short durations, but wide spread characteristics in Antecedent Dry Weather Period (ADWP) and maximum intensity.

In order to summarize and compare the runoff quality associated with each rainfall event, the event mean concentration (EMC – flow-weighted average of constituent concentration) has been evaluated. In [Table 2](#) the EMC values for each parameter are shown and the results concerning both monitoring sites are compared to the quality standards for discharges entering directly the receiving water bodies (Annex 5 - Italian Decree by Law 152/99 according to the EC Dir. 91/271).

As for the auto dismantler site, it emerges that the EMC values for TSS, COD and HC exceed the Italian quality standard in all monitored events: in particular TSS and COD mean values are 4 times higher than the standard ones (TSS = 80 mg/l, COD = 160 mg/l) while HC values are twice the standard value (HC = 5 mg/l). Among heavy metals copper, zinc and lead are on average below the above mentioned standards, even if copper and zinc exceed the standards in two events; on the contrary nickel, cadmium and chromium are only present in traces (several order of magnitude below the quality standards). It has to be noted that the heavy metals concentration values only refer to the dissolved fraction; no laboratory analyses have been performed on the particulate matters. However, taking into account the correlation between suspended solids and the particulate bound fraction of heavy metals, demonstrated by several studies ([Förster, 1996](#); [Sansalone and Buchberger, 1997](#); [Del Giudice et al., 2000](#)), together with the magnitude of particulate matters monitored in the present monitoring campaign, the total amount of heavy metal discharged into the receiving water bodies could be quite significant.

As for the gas station site, the most significant parameters are TSS and COD, whose concentration values exceed the quality standards in 4 over 5 events, however the mean values are lower than the half the auto dismantler facility ones. Zinc and copper are instead higher on average than the corresponding values of the other site of concern. The concentrations of total hydrocarbons are generally equal to 1 mg/l; this result is much lower than the expected ones according to data documented in the literature ([Schueler and Shepp, 1993](#)). This is due mainly to the characteristics of the monitored events (low rainfall intensity and depth), which didn't allow the pollutant wash-off by rain and transport into the drainage system and to the limited data set available.

The relevance of runoff pollution associated with the paved surfaces of production sites clearly emerges by comparing the results obtained during the present monitoring campaign

Table 1 Rainfall characteristics of the monitored events at the auto dismantler site

	total depth (mm)	event mean intensity (mm/h)	max intensity at 5' (mm/h)	duration (h)	ADWP (d)
min	1.4	1.8	4.8	0.6	1.3
max	15.8	14.6	72.0	2.8	37.3
mean	8.8	5.4	24.5	1.8	12.8
median	10.2	4.4	19.2	1.8	8.8

Table 2 Event Mean Concentration concerning the parameters monitored in the auto dismantler facility and gas station sites and the water quality standards for discharges entering directly the receiving water (Italian D.L. 152/99 according to the EC Dir. 91/271)

	Auto dismantler site			Gas station site			D.L.152/99
	mean	min	max	mean	min	max	standards
SST (mg/l)	378	187	894	125	44	193	80
COD (mg/l)	634	220	1074	310	162	472	160
HC _{tot} (mg/l)	12	5.3	26	1.2	1.0	1.6	5
Cu (μ g/l)	63.8	7.2	113.2	78.1	46.9	134.8	100
Pb (μ g/l)	29.6	1.9	70.7	2.8	1.9	4.1	200
Zn (μ g/l)	283.8	76.1	503.6	378.4	169.9	582.3	500
Cr (μ g/l)	5.9	0.8	16.9	–	–	–	2000
Ni (μ g/l)	24.8	7.7	58.0	–	–	–	2000
Cd (μ g/l)	0.5	0.4	0.8	–	–	–	20

with those collected in a previous study at the residential catchment of Villa Cambiaso in the town Genoa. The site of concern is a residential area with an extension of about 2800 m² including the ancient building of Villa Cambiaso and a parking lot of about 1000 m² (Gnecco *et al.*, 2005). Runoff quality data were collected in the years 2002–2003.

The EMC values obtained from data collected in both production sites are significantly higher than those from the residential site. It has to be noted that also the EMC values for TSS and COD from this latter site exceed the water quality standards. Similar results can be obtained by comparison with other quality data from urban catchment sites that are documented in the literature (Barrett *et al.*, 1995; Gromaire-Mertz *et al.*, 1999).

Therefore, the monitoring campaign carried out in the present study confirms that point pollution sources such as the external areas of production sites significantly contribute to the deterioration of receiving water bodies as well as the non point pollution sources. Their influence, considering the high pollutant load and the distribution on the territory, is not less important than the better-investigated non point pollution sources (such as road and roof surfaces).

Finally, it is interesting to note that from the data collected in both production sites, scarce correlation between TSS and COD concentration values have been observed. This result differs from the outcome of residential sites: a strong correlation with a corresponding COD/SST rate of 0.95 has been recorded in Villa Cambiaso which confirms the behavior observed in other urban experimental catchments (Artina and Maglionico, 1997) (Table 3).

Data elaboration results

In order to compare pollution runoff processes associated with different rain events, data collected during the monitoring campaign have been represented through the dimensionless

Table 3 Comparison between the EMC of runoff pollutants monitored at production sites and residential area

	Auto dismantler site	Gas station site	Urban catchment – Genoa, Italy		
	mean	mean	mean	min	max
SST (mg/l)	378	125	140	15	377
COD (mg/l)	634	310	129	11	281
Cu (μ g/l)	63.8	78.1	19.4	0.1	53.3
Pb (μ g/l)	29.6	2.8	13.2	6.1	23.3
Zn (μ g/l)	283.8	378.4	81.1	27.7	123.4

$M(V)$ curves that consist of plotting the cumulative fraction of the total pollutant mass vs. the cumulative fraction of the total runoff volume. In this representation the first flush phenomenon is considered to occur when the curve is above the bisector and its entity depends on the initial slope of the curve.

Figures 1 and 2 report the runoff processes occurred during the whole monitoring campaign and each graph concerns the behaviour of a specific pollutant.

As for the auto dismantler facility site (Figure 1) it emerges that the first flush of TSS occurs in 80% of the monitored events thus producing the wash-off of more than 40% of the total mass of suspended solids by 30% of the discharged runoff volume. It must be considered that the most significant concentrations of TSS showed up mainly at the beginning of the runoff process because of the combination of two phenomena: the solids washed off by runoff from the impervious surface and the deposits flushed out from

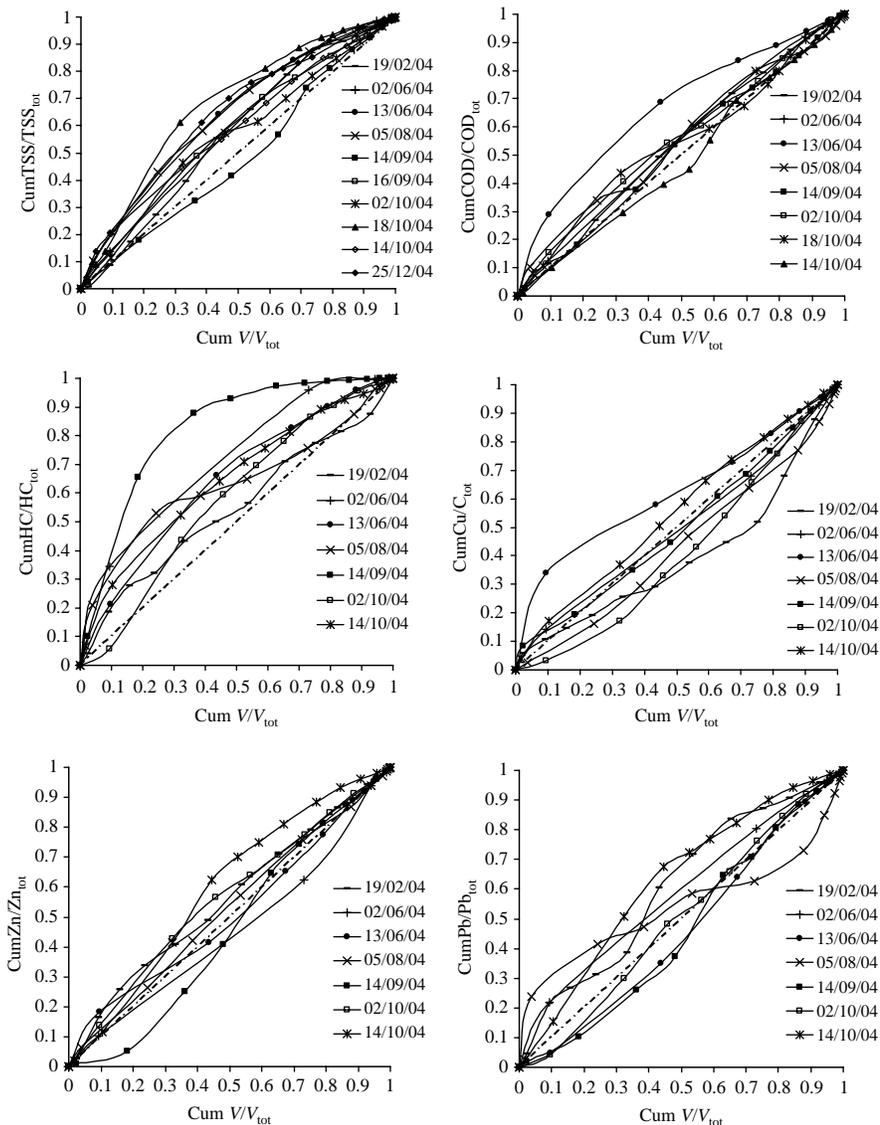


Figure 1 $M(V)$ curves for TSS, COD, total hydrocarbons and heavy metals in dissolved form in runoff resulting from the auto dismantler facility

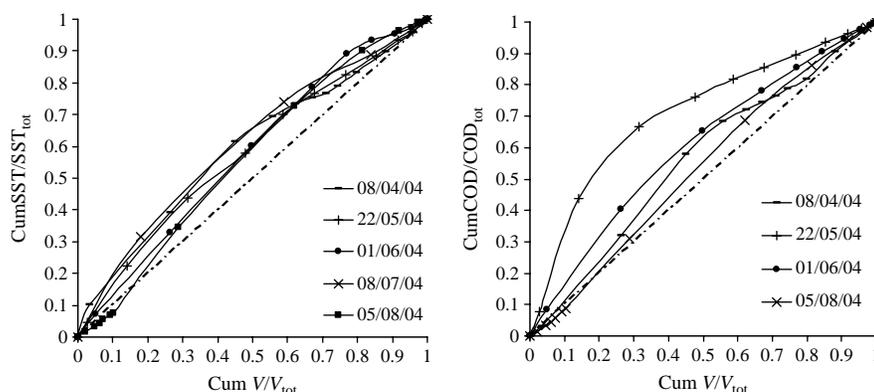


Figure 2 $M(V)$ curves for TSS and COD in runoff resulting from the gas station

pipes. The contemporary occurrence of both processes contributes to enhance the entity of first flush.

Although the dimensionless representation allows to compare different rainfall events in terms of the associated wash-off processes, no indication about the total pollutant load discharged into the receiving water bodies is provided therein. By comparison of two different events (13/06/04 and 05/08/04) characterized by the same first flush entity (50% of the total mass washed off by 30% of the runoff volume), it emerges that the EMC value produced in the second event for TSS is about twice the one of the first event ($EMC_{05/08/04} = 471 \text{ mg/l}$, $EMC_{13/06/04} = 241 \text{ mg/l}$).

The $M(V)$ curves of COD do not show a significant occurrence of the first flush phenomenon: all curves (except for the event of 13/06/04) are close to the bisector to indicate that the concentration is constant during the storm event. Despite the absence of any significant first flush, the EMC values for COD range from 220 mg/l to 1074 mg/l.

As for the total hydrocarbons the magnitude of the first flush is pointed out by the graph of Figure 1: in 6 over 7 events 30% of runoff washed off between 40 and 60% of total hydrocarbons. In the most significant event (14/09/04) during which 80% of the mass was associated with 30% of runoff, the event mean concentration was equal to 26 mg/l, the maximum value recorded during the whole monitoring campaign.

No clear behaviour emerges from the $M(V)$ curves of Cu, Zn and Pb. The nature of heavy metals (dissolved or particulate bound) is also connected to the specific environmental conditions (pH, temperature) thus causing fluctuations in the wash-off processes of the dissolved fraction of Cu, Zn and Pb.

As for the gas station site (Figure 2) it generally emerges the occurrence of first flush for TSS. Contrary to the auto dismantler site, the first flush phenomenon also occurs for COD. However, due to the limited data set available, these results must be considered as preliminary.

As regard the building-up process, from data collected in the auto dismantler facility site, no correlation between the Antecedent Dry Weather Period (ADWP) and the total amount of pollutant mass discharged during the rainfall event has been observed. This behaviour clearly emerges by comparison of the monitored rainfall events with different ADWP. For example, the event of August 5th and the one of September 16th were characterized by similar runoff discharge and total runoff volume but strong differences in terms of ADWP: 29.3 days in the first event while only 1.3 days in the second case. In spite of this difference, both rainfall events were characterized by ECM values of about 450 mg/l for TSS.

On the contrary the pollutant building-up on urban surfaces is strongly influenced by the antecedent dry weather period: this parameter has a primary role in the well-known relationships (linear or exponential) that are used to describe this process for modelling purposes in the literature (Huber and Dickinson, 1988).

Conclusions

Since February 2004 stormwater runoff quality associated with the paved surfaces of a gas station and an auto recycler and dismantler facility nearby Genoa, Italy, has been investigated.

When compared to the results obtained from the monitoring of runoff from residential areas, the higher concentration values registered for TSS, COD, HC, Zn and Cu show the relevance of hot-spots pollutant sources in the deterioration of receiving water bodies. The EMC values for both production sites (and particularly for the auto dismantler) exceeded the quality standards for discharges entering directly the receiving water bodies (Italian Decree by Law 152/99 according to the EC Dir. 91/271). Differing from residential areas, scarce correlation between TSS and COD concentration is observed in runoff from both production sites. From the analysis of the data collected, differences in pollutant generation and wash-off processes between point and non-point pollution sources clearly emerge.

Contrary to non-point-pollution sources (roads, roofs, parking lots), the build-up process seems to be affected by the specific production sites activities rather than the ADWP, which generally plays an important role. Furthermore, the influence of hydrological parameters such as rain intensity on the wash-off process does not emerge. Design criteria for water runoff management devices, presently based on the assumption that the first portion of stormwater runoff is the most polluted, must take into account such differences.

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