



HAL
open science

Modelling approach to assess the variation of pollutant mass flow rates during storm events

P. Piro, M. Carbone

► **To cite this version:**

P. Piro, M. Carbone. Modelling approach to assess the variation of pollutant mass flow rates during storm events. Novatech 2010 - 7ème Conférence internationale sur les techniques et stratégies durables pour la gestion des eaux urbaines par temps de pluie / 7th International Conference on sustainable techniques and strategies for urban water management, Jun 2010, Lyon, France. pp.1-10. hal-03296456

HAL Id: hal-03296456

<https://hal.science/hal-03296456>

Submitted on 22 Jul 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Modelling approach to assess the variation of pollutant mass flow rates during storm events

Approche de modélisation pour évaluer la variation des taux de débit massique de polluants au cours d'une averse

Patrizia Piro, Marco Carbone

Università della Calabria (Italy) - Dipartimento di Difesa del Suolo
(patpiro@dds.unical.it – marco.carbone@unical.it)

RÉSUMÉ

La connexion entre l'hydrologie et les phénomènes d'accumulation, le lessivage des sols et le transport de polluants dans un bassin versant urbain au cours d'une averse impacte fortement sur la capacité de traitement du réseau d'assainissement urbain.

Au cours des dernières années, la notion de premier flot a été introduite et développée pour l'analyse de l'interaction entre l'hydrologie et le transport des polluants. L'une des principales définitions du premier flot vient de l'analyse des courbes $m(v)$. En effet, les courbes $m(v)$, qui indiquent la répartition du volume de polluants par rapport à la masse dans les rejets d'eaux pluviales, sont habituellement utilisées pour comparer les rejets de polluants issus d'épisodes pluvieux et de bassins versants différents. L'approche utilisée dans le présent document afin de définir et d'analyser les courbes $m(v)$ a été présentée par Sansalone et Cristina (2004) qui ont défini les concepts d'événements limités en débit et en masse. La reconnaissance des deux comportements a été appliquée à des événements observés sur le bassin versant Liguori (LC) dans la zone urbaine de Cosenza.

Afin de contribuer à l'étude et l'analyse de la variabilité basée sur l'épisode en fonction des courbes $m(v)$, le modèle mathématique SWMM EPA (Environmental Protection Agency - Storm Water Management Model) a été initialement calibré pour une série déterminée de paramètres liés à la variabilité des épisodes et la différence entre les courbes $m(v)$ observées et simulées a été analysée. Les résultats ont indiqué une bonne corrélation entre les courbes $m(v)$ observées et simulées.

ABSTRACT

The connections between hydrology and phenomena of accumulation, washoff and pollutant transport in an urban catchment during a storm event deeply affect the treatment of urban drainage.

In recent years, the concept of first-flush was introduced and developed to analyze the interaction between hydrology and transport of pollutants. One of the most important definitions of first-flush derives from the analysis of the $m(v)$ curves. Indeed the $m(v)$ curves, indicating the distribution of pollutant mass vs volume in stormwater discharges are commonly used to compare pollutant discharges from different rainfall events and catchments. The approach used in this paper to define and analyze the $m(v)$ curves was introduced by Sansalone and Cristina (2004) who defined the concepts of flow limited and mass limited events. These two different behaviors have been applied to events observed in the Liguori Catchments (LC) in the urban area of Cosenza.

In order to contribute to the study and analysis of the event-based variability of the $m(v)$ curves, the mathematical model SWMM EPA (Environmental Protection Agency - Storm Water Management Model) was initially calibrated for a fixed set of parameters to changes of the event and the difference between observed and simulated $m(v)$ curves was analyzed.

The results showed a good correlation between $m(v)$ observed and simulated curves.

KEYWORDS

First-flush, CSO, Pollutant transport, Modelling, Hydrological data-base

1 INTRODUCTION

The system of modern life has produced a large alteration of the natural environment and specifically the administration of the water cycle in urban areas has become a complex problem: population growth and economic activity, legislative pressure and economic links require not only high-tech and efficient equipments, but also appropriate methods for the control, development and functionality of the system.

During rain periods, great quantities of pollutants are removed by urban surfaces and discharged, through spillways, into natural and artificial watercourses, without treatment.

Different types of roads with different traffic lead to very dissimilar conditions (Muschack, 1990). To simplify the overall view it can be said that the first flush carries from the roads to the receiving body both dissolved contaminants and solid particles, which may be originally toxic or have absorbed organic and inorganic toxic compounds (Ellis, 1989 and 2000).

The hydrographic conditions adjacent to road infrastructures and the intensity of weather events can affect the transport of pollutants in the water receiving body (Croke et al., 2004). Indeed the effect of road washing and pollutant potential transport is amplified by a direct hydraulic connection and by the release of the first flush (Sriyaraj and Shutes, 2001, Gnecco et al, 2006).

The mechanism of transport, which is of greater importance, is, therefore, associated with sediment and this condition is fundamental in the choice of the most efficient disposal systems, which consist in trapping the solid fraction facilitating sedimentation (Ellis, 1991).

In European countries the problem of reducing combined sewer overflows (CSO) historically arose in situations where the use of water bodies had a social or economic value: protection of drinking water resources, protection of bathing, etc.

But construction and operation/maintenance of efficient and effective stormwater drainage facilities require application of modern technology that reflects recent advances in research and development. Before any potential treatment strategy can be chosen, we need to examine both hydrologic and water-quality characteristics (Piro et al, 2007).

Regarding water treatment and mixed rain, the best solution is to convey water from both rain tanks to overflow treatment plants to optimize the performance of both devices (O'Connor and Field, 2002a).

As already pointed out by other authors (Chocat, 1997; Sakrabani et al., 2005; Piro et al, 2007), much of the pollution load of rainwater can be mixed together with particulate matter from other sources such as roads and other paved surfaces. Therefore the selection and development of design criteria for stormwater treatment may be based on physical processes.

For the cited reason, the study of the pollutant variability associated to each event in different environmental conditions appears to be very important; most of the analyses on the pollutant transport have focused on the study of the $m(v)$ curves (Maidment, 1993; Wanielista e Yousef, 1993; Deletic, 1998; Wu et al., 1998; Appel e Hudak, 2001, Lee e Bang, 2000; Sansalone and Cristina, 2000; Farm, 2002).

The interaction between hydrology and pollutant transport was studied by Sansalone and Cristina (2000) that introduced the concepts of mass limited (ML) and flow limited (FL) events, defining these behaviors as possible in the dynamics of pollutants transport in urban area.

An observed series of ML and FL events, drained by the combined sewer system of the Liguori Catchment (LC) in Cosenza, was examined in this study. In particular, after the physical differentiation of the events in ML or FL, for each events the fitting with exponential and linear relationship was examined (Sansalone and Cristina, 2000).

2 OBJECTIVES

In order to propose practical solutions, it is necessary to study the distribution of the pollutant load vs volume in stormwater effluents through a statistical approach, but to do this we need a large quantity of events.

The fundamental purpose of this research study was to analyze the transport phenomena in a combined sewer system using the mathematical model SWMM to better understand the strategy to use to minimize the overflow impact, and to better define the pollutant transport characteristics, and

therefore the ML or FL behaviour, in a catchment without a long series of water quality sampling.

The first step was to examine the previously obtained water-quality characteristics and runoff hydrograph of the experimental site. The second and main step was to compare the analysis of the behaviour in measured flow or mass limited events with those deduced from the urban drainage model USEPA-SWMM (Storm Water Management Model from United States Environmental Protection Agency) after calibration and validation of the model on 8 storm events observed in the experimental urban catchment.

3 METHODOLOGY

3.1 Experimental site characteristics

The experimental urban catchment, called “Liguori”, employed in this study, is located in Cosenza, Southern Italy. The catchment elevation ranges between 205 m a.s.l. and 431 m a.s.l., its surface area is 413.62 ha, consisting of buildings (10,2%), roads (37.6%) and a wide natural area (51.4%). The urbanized catchment contributes wet weather flow from 200 hectares and supports a population of 50,000. Originally, the main drain was a natural stream; today, due to urbanisation, its urban reach has become a combined sewer main section. Figure 1 shows the catchment map.

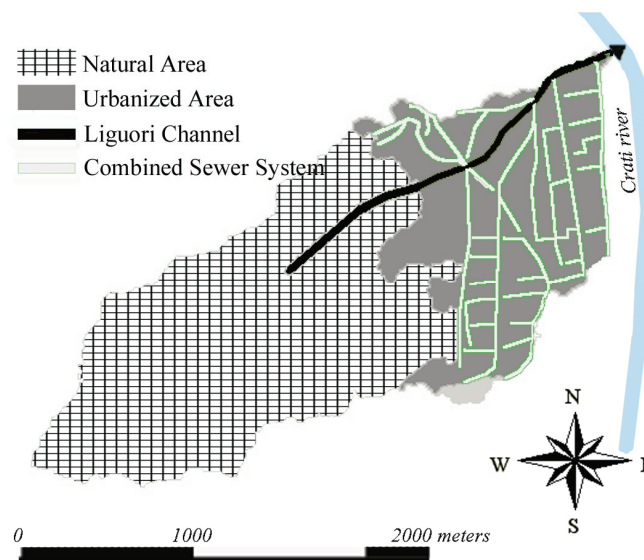


Figure 1. Combined sewer system and experimental urbanized Liguori catchment of Cosenza

Water coming from the catchment natural area, at the beginning of the city, is collected in a trapezoidal channel. At 234 m a.s.l., near a large parking area, it meets a pipe that conveys the water to the point where the polycentric section begins. Upstream to its outfall into the Crati river, a sewer collector intercepts the urban water and conveys it to the waste water treatment plant (WWTP).

Several studies have been carried out by the University of Calabria for many years and further details can be found in previous works (Piro, 2007; Piro and Sole, 2001).

3.2 Hydrologic-Data and Collection Stormwater-Runoff Sample Analysis

Table 1 summarizes the main values measured for each rainfall runoff events.

Quality characteristics were assessed through sample withdrawal and laboratory tests. During stormwater the samples were withdrawn through an automatic sampler installed at the outfall section, which was calibrated to start when the level in the collector increased markedly. An electrical device, consisting of two electrodes, one dipped into the water and the other placed on one stirrup berthed to the side of the channel, drives the process: when the level in the channel rises as a consequence of the atmospheric precipitations, the water touches the external electrode and closes the circuit with the other immersed electrode. During dry weather the samples were withdrawn manually and frequency was arranged every 30 minutes. A 490-ml volume bottle was withdrawn for each sample, and the samples were analysed at the Soil Defence Department.

Event	Rainfall duration (min)	Runoff duration (min)	Rainfall depth (mm)	Maximum rainfall rate (mm/h)	t_p (min)	t_r (min)	Q_p (m ³ /s)	V (m ³)	V_b (m ³)	Q_{bm} (m ³ /s)
24 March 1998	595	462	1.1	6.0	182	47	1.38	7503	3826	0.11
28 April 1998	159	151	4.1	12.0	77	24	3.14	10125	602	0.05
2 October 2000	222	131	1.5	2.4	49	13	0.56	632	2316	0.23
1 November 2000	103	92	6.2	60.0	22	11	4.66	5258	1079	0.18
18 December 2000	627	750	2.2	12.0	58	58	0.99	3844	7383	0.16
24 February 2002	605	684	10.6	3.0	234	120	1.36	7406	6029	0.13
29 January 2003	156	255	9.4	24.0	38	21	4.82	21646	3556	0.22
30 January 2003	207	241	9.2	24.0	97	79	5.02	17630	3357	0.22
t_p	time to Q_p measured from start of rainfall, [T]									
t_r	time to Q_p measured from start of runoff, [T]									
Q_p	volumetric peak flow rate, [L ³ T ⁻¹]									
V	total volume, [L ³]									
V_b	total base volume, [L ³]									
Q_{bm}	median volumetric dry weather flow rate, [L ³ T ⁻¹]									

Table 1. Hydrological statistics for the urban Liguori catchment

For each event, the following tests were performed on stormwater samples: BOD₅, COD, TSS, pH and conductivity. Hydrologic and water quality field data were collected during all sampled events at the experimental catchment. The rain events varied in duration, intensity, inter-arrival times and generated flows (ranging from the low-flow to high-flow capacity of the flume). Samples were analyzed for water quality parameters for all events. Table 2 shows the range of values measured for each event, for every constituent characterized.

Wet Weather event	Sample number	Range		
		TSS [mg/l]	COD [mg/l]	BOD ₅ [mg/l]
24 March 1998	8	27-344	144-157	15-250
28 April 1998	7	114-342	354-760	N/A
2 October 2000	26	118-1870	157-2607	96-655
1 November 2000	28	141-1333	160-1387	152-544
18 December 2000	34	50-193	101-310	45-122
24 February 2002	22	32-620	46-684	4-201
29 January 2003	29	83-4487	54-311	N/A
30 January 2003	29	102-1732	56-192	N/A

Table 2. Sampling data

3.3 Modelling

To estimate the production of pollutant loads associated with transport of generated runoff flows, the SWMM model was used. The SWMM allows modelling of any number of user-defined water quality constituents, dry-weather pollutant build-up over different land uses, pollutant washoff from specific land uses during storm events, direct contribution of rainfall deposition, reduction in dry-weather buildup due to street cleaning, reduction in washoff load due to BMPs (Best Management Practices), entry of dry weather sanitary flows and user-specified external inflows at any point in the drainage system, routing of water quality constituents through the drainage system, reduction in constituent concentration through treatment in storage units or by natural processes in pipes and channels (US EPA, 1992).

To ensure reliable results, environmental models require calibration and verification. In the present study, the input data and parameters required by the SWMM model to simulate drainage flow hydrographs are physiographic characteristics of the catchment (e.g., area and slope), geometric characteristics of the sewer pipes (diameter, length, slope and material), and the hydrological/hydraulic parameters such as the width of the subcatchments, catchment roughness described by the Manning coefficient, surface depression depths, and the infiltration rates for pervious areas.

In this study, the flow calibration parameters taken into consideration were: surface roughness of the

impervious (N-Imperv) and pervious (N-perv) surfaces in the catchment, and the depths of surface depressions on impervious (Dstore-Imperv) and pervious (Dstore-Perv) areas.

Following the calibration of modelled flows, water quality subroutines in the SWMM model were also calibrated, assuming the characteristics of the catchment (land use, physical propriety, pollutant inputs due to precipitation, build up and wash-off rates) constant for all storms, according to previous studies of literature (Marsalek J., 1976).

In the SWMM model the routing of quality parameters is performed by using the integral solution for the output from a completely mixed conduit volume. Each pollutant is assigned a specific gravity and particle size distribution. If the specific gravity is less than or equal to 1.0, the pollutant is considered to be entirely suspended (or dissolved) and not subject to scour and deposition (US EPA, 1992). During the simulation scour and deposition are simulated using Shields criterion (Graf, 1971) to determine the critical diameter for incipient motion and deposition. Shields himself observed the process of initiation of motion to be stochastic in nature, so that there is no true "critical condition" at which motion suddenly begins; in fact, data on critical shear stress are based upon arbitrary definitions of critical conditions by several investigators (US EPA, 1992).

In this work the mass-limited behavior is seen as indicative, not so much as physical aspect, but rather a summary of the event feature that takes into account the hydrological aspects, volume and rainfall intensity, and aspects of accumulation, runoff and mass transport in the catchment. In this context, in the opinion of writers, it is possible not take in account the mass not completely washed off during the previous events. To estimate the particulate matter (PM) pollutograph, two different land uses (residential and natural) were first identified. The amount of build-up (function of the number of preceding dry weather days) was computed using a first order exponential function. In this manner the build up follows an exponential growth curve that approaches a maximum limit asymptotically.

$$M_B = P_1 \times \left(1 - e^{-P_2 \times pdd}\right)$$

where, P_1 = maximum build up possible (mass per unit of Area), P_2 = build up rate constant (1/days) and pdd= number of previous dry days. To describe the properties associated with pollutant wash off over the land use during wet weather events the following exponential function was used.

$$M_W = P_3 \times q^{P_4} \times M_B$$

where, P_3 = wash off coefficient, P_4 = wash off exponent, q = runoff rate per unit area (mm/hour), and B = pollutant build up in mass (kg) per unit area. Wash off mass units are the same as those used to express the pollutant concentration (milligrams).

The goodness of fit of modelled hydrographs and pollutographs is described in Table 3 by the linear regression correlation coefficient R^2 .

The data in Table 3 and Figures 2 and 3 indicate that the agreement between observed and modelled hydrographs and pollutographs is fairly good. Such results confirm the validity of the calibrated SWMM model and its ability to serve as a good prediction tool.

Wet Weather event	Quantity Simulations	Quality Simulations
	R^2	R^2
Calibration		
24 March 1998	66%	90%
28 April 1998	87%	82%
2 October 2000	78%	90%
1 November 2000	95%	83%
24 February 2002	70%	61%
29 January 2003	72%	80%
Validation		
18 December 2000	92%	81%
30 January 2003	83%	68%

Table 3. Linear regression correlation coefficient R^2 for SWMM calibration and validation storm events

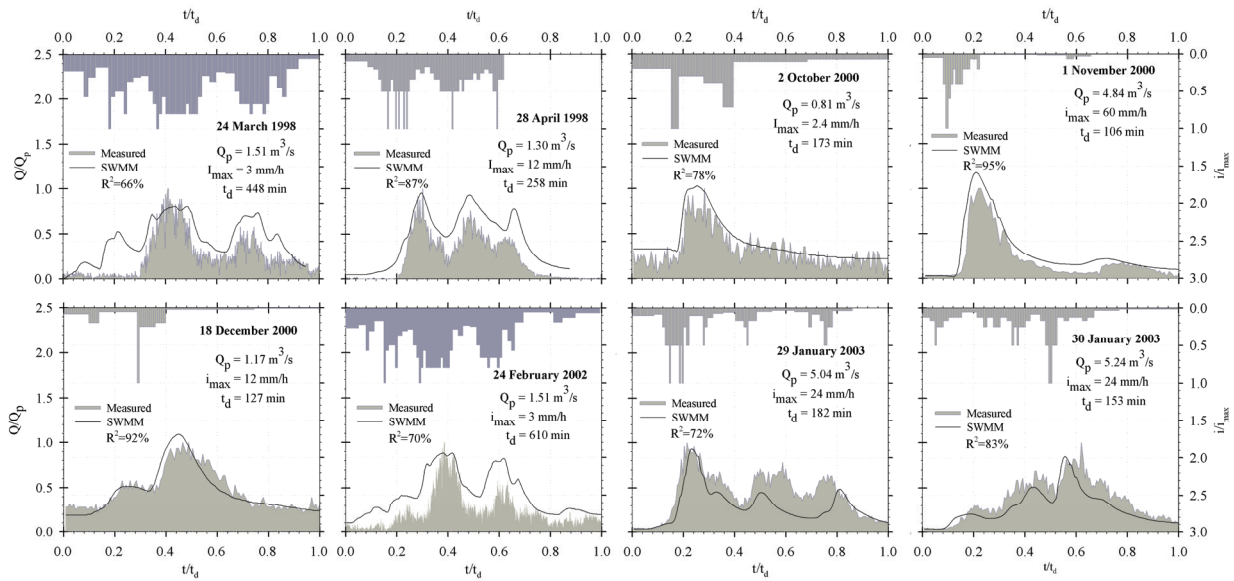


Figure 2. Event-based hydrology with hydrographs observed and simulated during the events for the urbanized LC

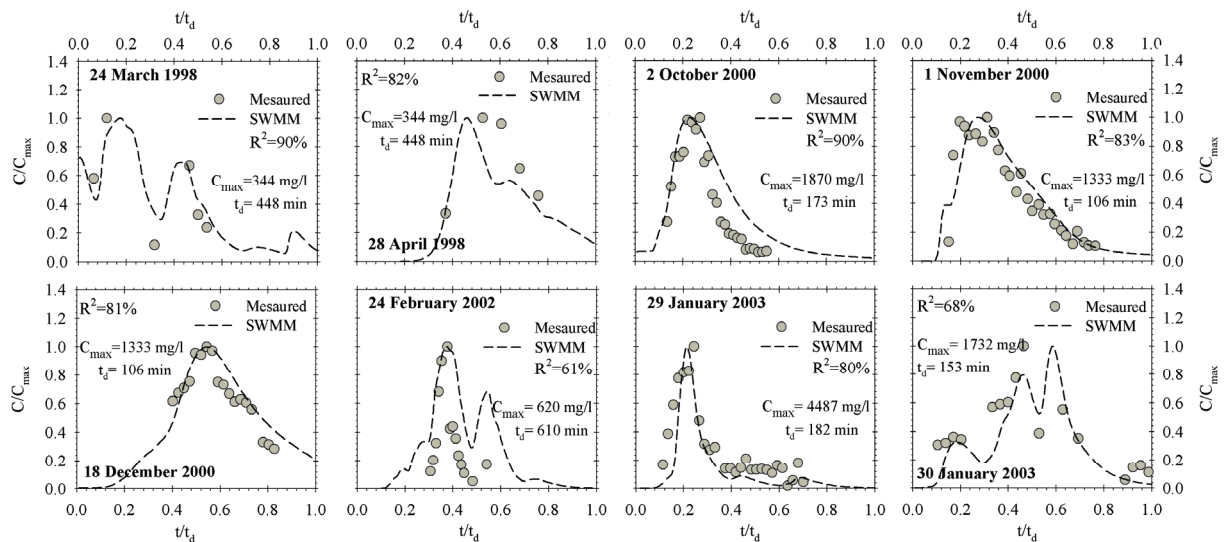


Figure 3. Pollutographs observed and simulated during the events for the urbanized LC

The SWMM parameters used are summarized in Table 4.

Parameter	n_{IMP} ($m^{1/3}/s$)	n_{PER} ($m^{1/3}/s$)	$d_{storeIMP}$ (mm)	$d_{storePER}$ (mm)	n ($m^{1/3}/s$)	P_{1R} (Kg/ha)	P_{1N} (Kg/ha)	P_2 (1/days)	P_3	P_4
Value	0.011	0.22	2.2	5	0.011	225	62.5	0.08	0.025	2.2
n_{IMP}	Manning's n for overland flow over the impervious portion of the subcatchment									
n_{PER}	Manning's n for overland flow over the pervious portion of the subcatchment									
$d_{storeIMP}$	Depth of depression storage on the impervious portion of the subcatchment									
$d_{storePER}$	Depth of depression storage on the pervious portion of the subcatchment									
n	Manning's roughness coefficient of the conduit									
P_{1R}	The maximum buildup that can occur for residential area									
P_{1N}	The maximum buildup that can occur for natural area									
P_2	Build up rate constant									
P_3	Wash off coefficient									
P_4	Wash off exponent									

Table 4. Calibrated SWMM parameters used in the model

3.4 Runoff Event Transport

The variation of the pollutant mass flow rates during storm events in sewer system is described by the hydrograph $Q(t)$ and the pollutograph $C(t)$ for each pollutant considered, where Q is the flow rate and C the concentration. In order to allow a comparative study of the pollutant mass flow rate for each event, the conceptual model expressing the normalized cumulative constituent mass as a function of the normalized cumulative flow is commonly used. This approach was introduced into stormwater event analysis by Marsalek (1976) for describing stormwater quality variations during events and detecting the occurrence of high concentrations (the first flush) during the initial parts of runoff. This function can be used to analyze the catchment response with respect to the first flush phenomenon (Marsalek, 1976; Bertrand-Krajewski et al., 1998; Deletic, 1998; Sansalone et al., 2004).

To analyze and classify mass transport the methodology suggested by Sansalone and Cristina (2004) was used.

When there is sufficient constituent mass available on the surface across the event duration, and the flow rate is the critical factor limiting the wash off process, the event is defined "flow-limited", in other words, as constituent mass delivery that is proportional to runoff volume. On the other hand, when at the latter portion of the event, there is not enough constituent mass available on the surface, and it would be the constituent mass which limits the wash off process, the event is defined "mass-limited", that is as disproportional constituent mass delivery of runoff volume, typically lower volume delivery relative to the amount of constituent mass delivered.

Defined the cumulative volume at time t , $V_T(t) = \sum_1^t V_j$, and the cumulative mass at time t , $M_T(t) = \sum_1^t M_j(TSS)$, where V_j and $M_j(TSS)$ are, respectively, the flow volume and the mass of TSS at time j , it is possible to observe that the first case emphasizes a linear relationship between $V_T(t)$ and $M_T(t)$, while the second case is described by an exponential relationship (Sansalone and Cristina, 2004).

The different behaviour between mass-limited and flow-limited events has clear implications for in-situ control of rainfall-runoff quality. For mass-limited event, there is a mass first flush so it is possible to size treatment measures to capture a proportion of the mass load, rather than an event volume and hence allow reduction in the size of the device needed, with more economical design for volume-based controls. For a mass-limited event, constituent mass remaining on the urban surface is the limiting factor, so it is possible to describe this behaviour with the following expression (Sheng et al, 2006):

$$\Sigma M = M_0(1 - e^{-k_1 \Sigma V})$$

where, ΣM is the cumulative constituent mass delivered [M]; ΣV is the cumulative volume [L^3]; M_0 is the constituent mass on the surface at the beginning of the rainfall-runoff event [M]; k_1 is the first-order coefficient [L^{-3}].

For a flow-limited event, it is the flow rate which is the critical factor limiting the entrainment and delivery process. Therefore the wash-off rate is uncorrelated to the constituent mass remaining on the urban surface. For flow-limited events the following expression was proposed (Sheng et al, 2006):

$$\Sigma M = k_0 \Sigma V$$

Where, ΣM is the cumulative constituent mass delivered [M]; ΣV is the cumulative volume [L^3]; and k_0 is the zero-order coefficient [ML^{-3}].

Summarizing, if the cumulative constituent mass versus cumulative volume curve follows an exponential pattern, the event is mass-limited; if the cumulative constituent mass versus cumulative volume curve follows a linear pattern, the event is flow-limited. These definitions provide a connection between the differentiation of rainfall-runoff delivery and the conventional wash off models.

4 RESULTS

4.1 Hydrological and quality characteristics

Continuous flow and rainfall measurements were recorded at intervals of one measurement per minute and figure 2 reports the hydrographs, with flow and rainfall intensity normalized for the storm

events studied. After each storm event was completed, hydrologic information was collected and reviewed. For each storm event the following parameters were calculated: rainfall and runoff duration, rainfall depth, rainfall intensity, peak flow rate (Q_p), runoff flow volume (V), base flow volume (V_b), mean flow base (Q_{bm}), t_p and t_r , times to Q_p , respectively measured from start of rainfall and from start of runoff. The hydrologic data for the sites during all storm events are summarized in Table 1.

The hydrographs show the normalized flow rate on the left Y-axis, the normalized rainfall intensity on the right Y-axis and the elapsed time, from begin of storm event, on the top and bottom X-axis. The hydrograph provides a visual representation of what is revealed during the event.

In evaluating the hydrological data, not all storm events occurred on the identical information, but there is a big variability of data. The values estimated for total rainfall height were 1.1 ± 10.6 mm, for maximum intensity were 2.4 ± 60 mm/h, for peak flow rate of runoff were 0.56 ± 5.02 m³/s.

Further, for runoff volume, a maximum value, 21,646 m³, on 29 January 2003 and a minimum value, 632 m³, on 2 October 2000 were observed.

Figure 2 shows the observed and simulated hydrographs for each event analyzed showing a good fitting, more than 70%, in 7 events of 8 (maximum on the 1st November 2000 and minimum on the 30th January 2003).

The charts in figure 3 show the observed and simulated pollutographs for each event analyzed showing a good fitting, more than 80% in 6 events of 8, with a minimum on 24 February 2002.

4.2 Event-based transport: Mass or Flow Limited

In order to analyze the transport, for each rainfall-runoff event, the $m(v)$ curve was used, so the cumulative mass of TSS (total suspended solids) was plotted as a function of the cumulative runoff volume. In each chart of figure 4 the dashed line shows the relationships between the normalized

cumulative mass of TSS, $m(t) = \frac{M_T(t)}{M_T(t_d)}$ and the normalized cumulative volume, $v(t) = \frac{V_T(t)}{V_T(t_d)}$,

and the shaded shapes depict the normalized hydrographs (i.e., the normalized flow rate, Q/Q_p ,

versus the normalized elapsed time, t/t_d , where t_d = event duration). These plots are representative of the transport exhibited in wet weather conditions. The case of the events observed on 29 and on 30 January 2003 is peculiar. While in terms of logic, a mass limited event would be followed the day after by another mass limited event, a clear Mass Limited event was observed on 29 January followed by a Flow Limited event on January 30. This result can be explained by the fact that in that period a tunnel was being excavated on the highway placed in the upper basin area. Therefore, between day 29 and day 30 it was likely that large quantity of particulate material was deposited in the channel.

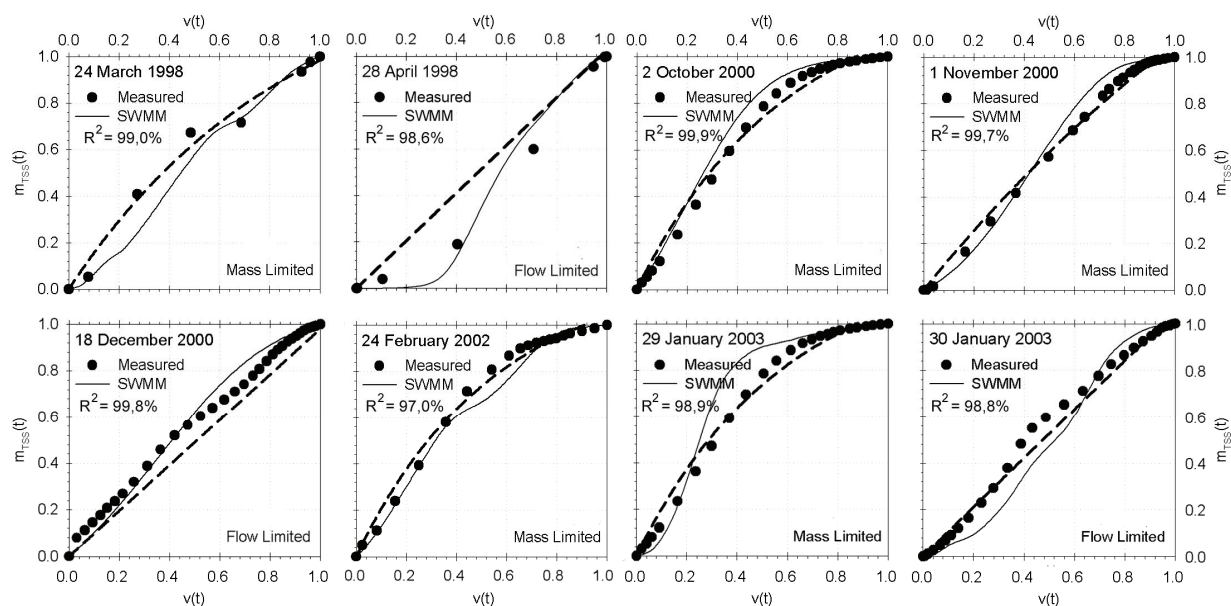


Figure 4. Transport of water TSS concentration observed and simulated during the events from urban LC

It is important to observe that data modelled through the SWMM model and measured data gave similar results as to transport behavior. In fact information about the type of transport obtained from the model are similar to those obtained from measured data. This is an important result because a model can be applied to the hydrological data-base in order to investigate with a statistical approach the variability and the occurrence of the type of transport. Experimental data results indicate that the transport of TSS mass was mass limited in 5 of 8 observations and flow limited in 3 of 8 observations; more precisely, the events of 24 March 1998, 2 October 2000, 1 November 2000, 24 February 2002 and 29 January 2003 were mass limited, the observations of --- 28 April 1998, 18 December 2000 and 30 January 2003 were flow limited.

The 28 April 1998 event shows characteristics that are not clearly classifiable with flow or mass limitation. This behavior is due to the specific characteristics of the catchment; in fact, the Liguori Channel is a combined sewer and, for several rainfall events, not particularly intense, at beginning was observed a reduced load mass contribution, compared with the volume drained.

Sampling surveys and studies are under way to investigate this phenomenon and the hydrological dependence of the Mass-Limited and of the Flow-Limited behaviour, in particular, from maximum rain intensity, peak flow, hydrograph shape, average slope of the catchment and average runoff volume.

The variability of the behavior for each measured characteristic confirm the results already obtained in other works (Sansalone J.J et al., 2004; Diaz-Fierros, 2002; Deletic A., 1998; Bertrand-Krajewski et al., 1998; Gupta and Saul, 1996; U.S. EPA, 1993; Thornton and Saul, 1987; Skipworth et al, 2000); this is a very important aspect when designing facilities that require a different approach for each characteristic in each event.

5 CONCLUSIONS

In the present work mass transport was studied in 8 rainfall-runoff events observed in the urban Liguori catchment (LC). The urban area of the catchment is highly impervious and the traffic is dominant.

The relationship between pollution transport and the hydrological characteristics of each event was analyzed, by differentiating the behavior in mass-limited and flow-limited. In most of the observed events the mass-limited behaviour prevailed. The TSS mass transport was clearly mass limited in 3 of 8 observations (2 October 2000, 1 November 200 and 29 January 2003), in the other cases the combination of several factors, hydrological, temporal and geometric, produced events for which the total flow volume had to be treated.

The difficulty to study the relationships between hydrological characteristics and pollutant transport in drainage networks by a probabilistic approach is due to the scarcity of quality data, because its collection is quite difficult. The aim of this research study is to overcome this problem by analyzing the potential of a mathematical model. Model calibration and validation have yielded good results both for quantity and quality parameters; correlations between observed and simulated hydrographs above 80% as well as correlations between observed and simulated pollutographs above 75% were measured.

The model gave satisfactory results even in the characterization of the events according to the mass-limited and flow-limited behaviour, in fact, correlation coefficients always higher than 97% were measured.

From this point of view, the analysis of the simulated $m(v)$ curves will be a good tool for the statistical approach which takes into account the variability of the phenomena, to facilitate the decision process when selecting a stormwater treatment strategy.

Additional research concerning these techniques and application of the probabilistic approach are in progress in the LC.

LIST OF REFERENCES

- Bertrand-Krajewski J.-L., Chebbo G., Saget A. (1998). "Distribution of pollutant mass vs volume in stormwater discharges and the first flush phenomenon", *Water Research*, 32 (8), 2341-2356
- Blanksby, J. (2002). "A review of the UK approach to measuring the performance of combined sewer overflows", *Urban Water* 4 , 191-198

- Calomino F., Mordente F., Piro P., Veltri P. (2000). *Il bacino sperimentale urbano del canale Liguori nella città di Cosenza*, Editoriale Bios, Cosenza
- Calomino, F., Piro, P. and Palma, G. (2003). "Combined sewer overflows into the Crati river (Cosenza, Italy) and retention storage sizing", Enhancing Urban Environment by Environmental Upgrading and Restoration, NATO Advanced Research Workshop, Rome, November 5-8
- Charbeneau, Randall J. and Barrett, Michael E. (1998). "Evaluation of methods for estimating stormwater pollutant loads", Water Environment Research, 70(7), 1295-1302
- Chocat B. (1997). *Encyclopédie de l'Hydrologie Urbaine*, Lavoisier TEC&DOC, Lavoisier – Paris.
- Deletic A. (1998). "The First Flush Load of Urban Surface Runoff", Water Research, 32(8), 2462-2470
- Diaz-Fierros T. F., Puerta J., Suarez J., Diaz-Fierros V. F. (2002). "Contaminant loads of CSOs at the wastewater treatment plant of a city in NW Spain", Urban Water, 4(3), 291-299
- Skipworth, P. J., Tait, S. J. and Saul, A. J. (2000). "The first foul flush in combined sewers: an investigation of the causes", Urban Water, 2(4), 317-325.
- Graf, W.H. (1971). *Hydraulics of Sediment Transport*, McGraw-Hill, New York.
- Gupta K., Saul A.J. (1996). "Specific relationships for the first flush load in combined sewer flows". Water Research, 30(5), 1244-1252
- Marsalek J., (1976): "Simulation of quality of urban drainage effluents" from the Proceedings of the Speciality Conference on "Environmental Impact of Irrigation & Drainage", Ottawa, Canada, 1976, Published by ASCE, New York, NY, USA, 564-579.
- O' Connor T. P., Field R. (2002a). "U.S. EPA CSO Capstone Report: control system optimization", 9th International Conference on Urban Drainage, Portland, OR, 08-13 September 2002
- O' Connor T. P., Field R. (2002b). "Control Strategy for Storm-Generated Sanitary-Sewer Overflows", 9th International Conference on Urban Drainage, Portland, OR, 08-13 September 2002
- Piro P., Sole A. (2001). *Analisi di reti di drenaggio urbano mediante l'uso dei GIS. Un'applicazione al bacino urbano del Liguori(CS)*, Editoriale BIOS, Cosenza
- Piro, P. (2007). *Il bacino sperimentale urbano del Canale Liguori nella città di Cosenza. Osservazioni sperimentali quali-quantitative nel periodo 1995-2003*, Editoriale BIOS, Cosenza
- Piro, P., Carbone, M., Garofalo, G. e Sansalone J. (2007a). "CSO treatment strategy based on constituent index relationships in a highly urbanized catchment." Water Science & Technology, 56(12), 85-91
- Piro P., Carbone M. and G. Garofalo, (2007b) "Distributed vs. concentrated storage options for controlling CSO volumes and pollutant loads", Accepted for publication in Water Practice & Technology, ISSN Online: 1751-231X, published by IWA Publishing
- Sakrabani, R. Ashley, R.M. and Vollertsen, J. (2005). "The influence of biodegradability of sewer solids for the management of CSOs", Water Science & Technology, 51(2), 89-97.
- Sansalone J.J., Hird J.P., Cartledge F.K. and Tittlebaum M.E.. (2005). "Event-Based Storm Water Quality and Quantity Loadings from Elevated Urban Infrastructure Impacted by Transportation" Journal of Water Environment Research, 77(4), 348-365
- Sansalone, J.J. (1997). "Infiltration as an urban source control for heavy metals and solids", XXVIIth IAHR Congress Proceedings, San Francisco, Aug. 1997.
- Sansalone, J.J. and Buchberger, S.G.. (1997). "Partitioning and first flush of metals and solids in urban highway runoff.", Journal of Environmental Engineering, ASCE, 123(2), 134-143
- Sansalone, J.J., and Cristina, C.M.. (2004). "First Flush Concepts for Suspended and Dissolved Solids in Small Impervious Watersheds." Journal of Environmental Engineering, ASCE, 130(11), 1301-1314
- Sheng, Y. Sansalone, J. and Calomino, F. (2006). "Estimation of solids loadings to rainfall-runoff unit operations using a unit pollutograph concept for source area watersheds" Water Science & Technology, 54(6-7), 363-369
- Thornton R.C. and Saul A.J. (1987). "Temporal variation of pollutants in two combined sewer systems", 4th International Conference on Urban Storm Drainage, Lausanne, Switzerland.
- U.S. EPA (1992). "Storm water management model, version 4:User's manual", Environmental Research Laboratory - Office of Research and Development - U.S. Environmental Protection Agency Athens, Georgia 30613.
- U.S. EPA (1993). Combined Sewer Overflows Control Manual, Report EPA-625R-93-007.
- Zhang, Haiping and Kiyoshi, Yamada (1998). "Simulation of Nonpoint Source Pollutant Loadings from Urban Area during Rainfall: an Application of a Physically-based Distributed Model." Water Science and Technology, 38(10), 199-206.