

## Filling and emptying cycles for stormwater storage tanks in separated systems

Cycles de remplissage et vidange des bassins d'orage dans les systèmes séparatifs

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### RESUME

Cet article décrit comment le niveau annuel de ruissellements transférés dans les bassins d'orage est influencé par les règles d'exploitation, leur capacité spécifique par bassin versant imperméable, la rétention des surfaces de bassins versants et l'intervalle minimum entre événements. Les trois séries de précipitations réelles différentes étudiées dans les essais numériques semblent donner des résultats similaires. De plus, la distribution de probabilité gaussienne se révèle en accord avec les niveaux annuels de ruissellements collectés, ce qui facilite la prévision de leurs quantiles pour une probabilité donnée de non dépassement (ou probabilité de dépassement). A des fins pratiques, il s'agit là d'un élément d'information très intéressant pour les exploitants d'usines de traitement des eaux usées qui doivent gérer les premiers flux pollués post-précipitation qui sont collectés et stockés dans des bassins d'orages urbains.

### ABSTRACT

This paper investigates how the annual runoff depth intercepted by urban stormwater on-line storage tanks is influenced by their running rules, their specific capacity per impervious catchment area, the depression storage on the catchment surfaces and the minimum inter event time. But, surprisingly, the three different real rainfall series considered in the numerical tests seem to yield quite similar outcomes. In addition, the Gaussian probability distribution is found to be a good fitting of the annual intercepted runoff depths, allowing an easy forecast of their quantiles for a given probability of non-exceedence (or probability of exceedence). For practical aims, this is a very interesting piece of information for the runners of wastewater treatment plants who are supposed to be in charge of dealing, after rainfall events, with the first foul flush volumes intercepted and stored into the urban stormwater tanks.

### KEYWORDS

Separated system, Storage tank, Stormwater management.

## 1 INTRODUCTION

Many recent studies, listed by Paoletti and Sanfilippo (2004), have demonstrated that most of the pollution loads discharged by urban drainage systems to receiving bodies during a year are concentrated in few dozen days of wet weather, especially in case of rainfall events with short durations and relevant intensities. In fact, during such events, the runoff waters wash off the deposits previously built up in dry weather on the catchment surfaces; consequently, the sewerage systems deliver large amounts of pollutants, through their overflows, directly to the receiving bodies. Moreover, this happens for both separated and combined networks, though with some differences in the pollution features (Brombach and others, 2004). In principle, tanks and sewer overflows with a design specifically aimed to control first foul flush in urban drainage networks can reduce both the frequency and the amount of polluted overflow spills in wet weather. However, huge specific capacities would be required to avoid spills at all, so huge to become unacceptable in terms of both integration in the urban areas and costs, except situations where the receiving body has a high environmental value and vulnerability and/or proper interventions for stormwater management have been planned before building the urban centre (Esser and others, 2004).

Some Authors have already pointed out the opportunity of a statistical approach to such problems (Adams and Papa, 2000; Bacchi and others, 2005), while other Authors have shown the relatively short time required to empty first flush storage capacities in comparison to the minimum inter event time when the latter is at least one day long (Ciaponi and others, 2005).

Hence, it looks essential to analyse how different possible running rules of the continuous filling and emptying cycles, for the usually limited available first flush storage capacities, can influence the impact of overflow spills on the water quality of receiving bodies. To this aim, the first aspect to be assessed is of course the reduction of the volume and the number of the overflows delivered to receiving bodies without treatment; and, afterwards, the reduction of the related pollution loads and shocks (Adams and Papa, 2000; Faram and others, 2004; Mourad and others, 2005).

This paper is focused on comparing the effectiveness of first foul storage capacities in the stormwater runoff networks of separated systems, for the key issue of reducing the overflow volumes. Such an analysis is developed on the basis of:

- three different possible running rules which can be adopted for the continuous cycles of filling and emptying of the storage capacity for a given rainfall series;
- specific storage capacity per impervious catchment area:  $w = 2.5, 5$  and  $7.5$  mm;
- depression storage on the catchment surfaces:  $DS = 0, 1, 2, 3, 4$  and  $5$  mm;
- chosen minimum inter event time which can be assumed to define a rainfall event as independent in terms of water quality:  $IET = 1, 2, 3, 4, 5, 6$  and  $7$  days;
- three different rainfall series, regarding respectively Milan (in the Po Valley), Candoglia (in the Prealps) and Pallanza (on the lakeshore of Lake Maggiore).

Indeed, a future development of such kind of analysis is already under preparation to study the much more complex situations that happen in combined sewers, where dry weather flow rates and overflow discharge threshold ratios are of course very relevant additional parameters influencing the phenomena, too.

Nevertheless, the analysis of the environmental benefits allowed by just on-line stormwater runoff networks of separated systems is believed to be very significant: both from a theoretical point of view because it shows the influence of the mentioned parameters (running rules, IET,  $w$  and  $DS$ ) and from a practical point of view because directly applicable to industrial areas, port and airport surfaces, roads and parkings.

## 2 METHODS

### 2.1 Running rules

The three above mentioned running rules for the stormwater storage tanks are named "A", "B" and "C" and hereby described in detail.

For all those rules, it is assumed the simple hypothesis that the minimum threshold of rainfall depth defining a single event is equal to the specific storage capacity.

#### 2.1.1 Rule "A" - Storing every first foul flush rainfall, soon emptying

Rule "A" consists in accepting into the tank every rainfall event, including the ones with a depth lower than a given minimum threshold, then starting to empty the tank soon after the end of each one of them. Apparently, such a rule could be affected by the difficulty of recognizing when the ongoing rainfall event is finished and therefore the emptying procedure must start. So, in practice, the emptying procedure must start after a dry period shorter than the minimum IET, i.e. shorter enough to completely restore the availability of the storage capacity when the minimum IET is passed.

#### 2.1.2 Rule "B" - Storing first foul flush of only rainfall events, soon emptying

Rule "B" consists in accepting into the tank only rainfall events with a depth higher than a given minimum threshold, then starting to empty the tank soon after the end of each one of them. Also such a rule is affected by the difficulty of recognizing when the ongoing rainfall event is finished and therefore the emptying procedure must start.

Moreover, rule "B" is affected by the much bigger additional difficulty of understanding a priori if the ongoing event is having a depth lower or higher than the given minimum threshold. Thos is the reason why such a rule is, indeed, very unlikely for practical applications. Nevertheless it is considered here anyway, as an interesting theoretical benchmark.

#### 2.1.3 Rule "C" - Storing every first foul flush rainfall, emptying only when full

Rule "C" consists in accepting into the tank every rainfall event, including the ones with a depth lower than a given minimum threshold, then starting to empty the tank just soon after the end of the rainfall which eventually fills it up. Such a rule is the simplest to be implemented in practice, but can cause bad smell and sedimentation in the tank when there is a relatively long wait from the end of a rainfall event leaving the same tank just partially full to a subsequent event that completes the storage filling and then makes the emptying procedure start.

#### 2.1.4 Storage tank emptying

It is assumed that the emptying process of the storage tank, once the adopted rule has commanded it to start, is completed quickly enough to make all the capacity fully available before the minimum IET is passed. In fact, for example, even a 7.5 mm volume can be emptied by an outflow rate equal to just 1 l/(s·ha) in 20.8 hours, which is less then the lowest minimum IET considered in this study (i.e.: 24 hours).

### 2.2 Depression storage emptying

It is assumed that the depression storage depth is always completely available when a minimum IET is passed after the last rainfall droplet, whichever are respectively the values of minum IET and depression storage and the adopted running rule ("A", "B" and "C"). This involves that, anyway, only after a minimum IET a rainfall depth  $h$ :

- will be reduced of an amount equal to DS if  $h \geq DS$ ,
- will completely disappear if  $h < DS$ .

### 2.3 Tested rainfall series

Three different Italian real rainfall series have been used, regarding respectively:

- Milan (in the Po Valley), 21 years from 1971 to 1991;
- Candoglia (in the Prealps), 15 years from 1990 to 2004;
- Pallanza (on the lakeshore of Lake Maggiore), 14 years from 1992 to 2005.

The resolution of their original data is one minute and 0.2 mm, while isolated Tippings (i.e.: 0.2 mm with at least 1 hour before and after) are discarded. Once discarded the isolated Tippings, the annual and monthly mean rainfall depths (Fig. 1a) and number of events (Fig. 1b) of the three series look significantly different, especially comparing the series of Milan with the ones of Candoglia and Pallanza, where there are larger rainfall depths and numbers of events. Furthermore, the occurrences of Candoglia have wider standard deviations in comparison to the ones of Pallanza and Milan.

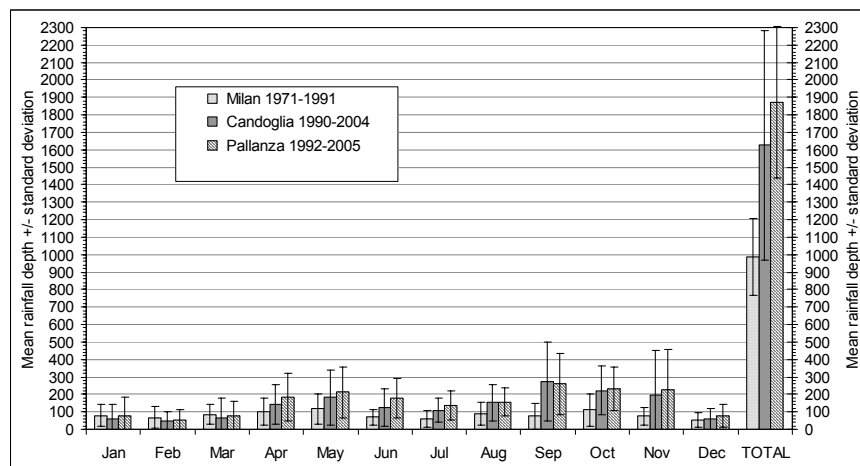


Fig. 1a - Annual and monthly depths (mean and st. deviation) of the tested rainfall series

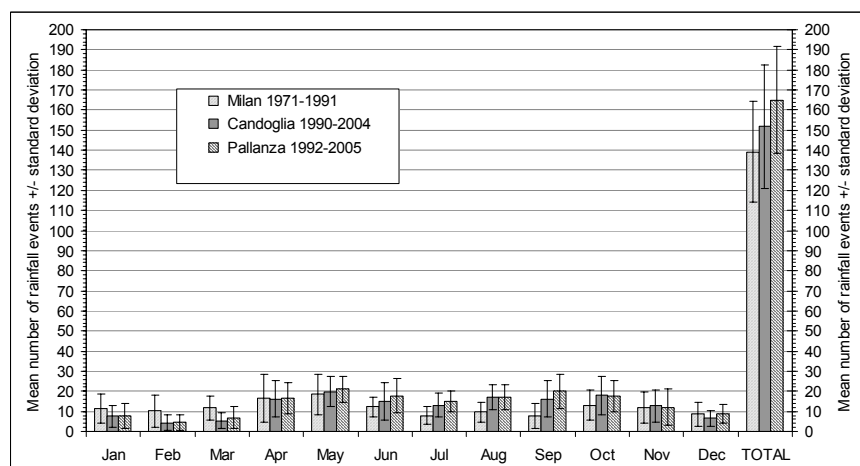


Fig. 1b - Annual and monthly number of events (mean and st. dev.) of the tested rainfall series

### 3 RESULTS AND DISCUSSION

#### 3.1 Annual average intercepted runoff depths

The annual average intercepted runoff depths for the three considered rainfall series are shown by Fig. 2a, Fig. 2b and Fig. 2c, in case respectively of DS = 0 and running rule "A", "B" or "C", each one of them with storage capacity  $w = 2.5, 5.0$  and  $7.5$  mm.

The following general effects can be observed:

- the influence of the chosen minimum IET and tank capacity  $w$  is very relevant;
- the differences are very small among the three considered rainfall series;
- the intercepted volumes are quite the same for rules "B" and "C", while they are more or less 20% higher in case rule "A" is adopted instead of rule "B" or "C".

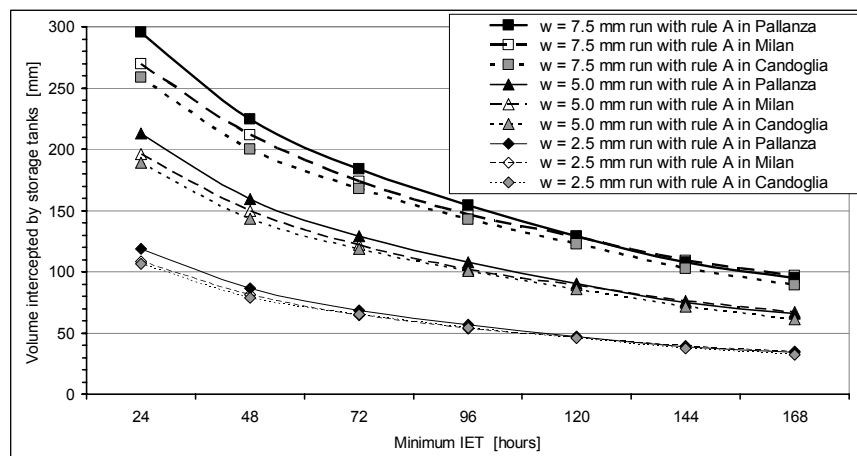


Fig. 2a - Annual average intercepted runoff depths obtained following the running rule "A"

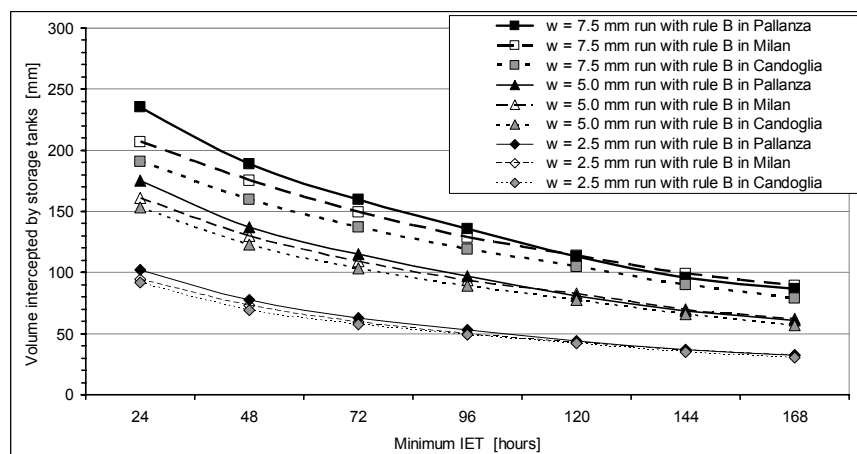


Fig. 2b - Annual average intercepted runoff depths obtained following the running rule "B"

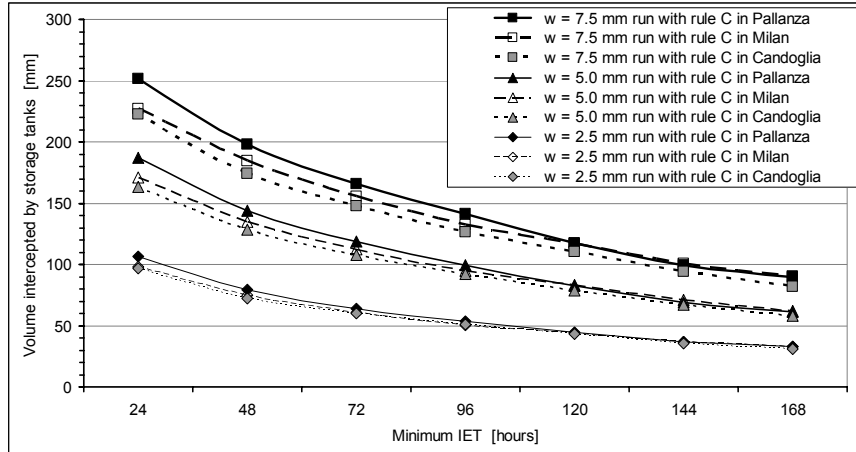


Fig. 2c - Annual average intercepted runoff depths obtained following the running rule "C"

### 3.2 Probability distribution of annual intercepted runoff depths

The analysis of the statistical behaviour of the annual intercepted runoff depth shows that it can be perfectly fitted by the Gauss distribution for each one of the considered cases, according to the fact that this is a kind of normal random variable because of the large number of rainfall events per year. In particular, Fig. 3 reports the annual intercepted runoff depth when having DS = 2 mm, w = 5 mm and running the tanks according to rules "A" and "C" for the rainfall series of Milan and a minimum IET = 48 hours and 96 hours. So, such a chart can be read to forecast the expected quantile of the intercepted annual runoff volume for a given probabilistic level or, on the contrary, the probabilistic level for a given quantile of the intercepted annual runoff volume.

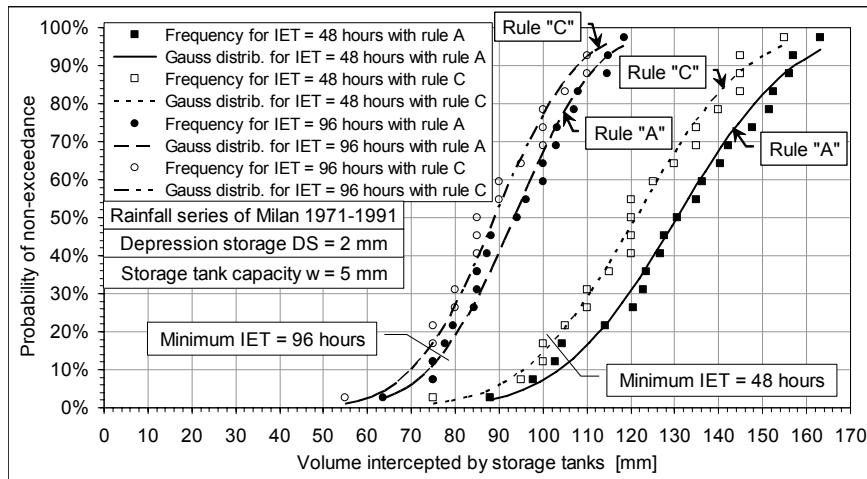


Fig. 3 - Probability of non exceedance for runoff volume intercepted by on-line stormwater tanks having w = 5 mm run with rules "A" and "C" considering the rainfall series of Milan with DS = 2 mm and a minimum IET = 48 hours and 96 hours

### 3.3 Influence of depression storage

Fig. 4 gives just an example (in case  $w = 5$  mm and the tanks are run with rules "A" and "C" considering the rainfall series of Milan and a minimum IET = 48 and 96 hours) of the relevant reduction of the volume intercepted by stormwater tanks thanks to the depression storage, which subtracts large part of the runoff caused by small rainfalls.

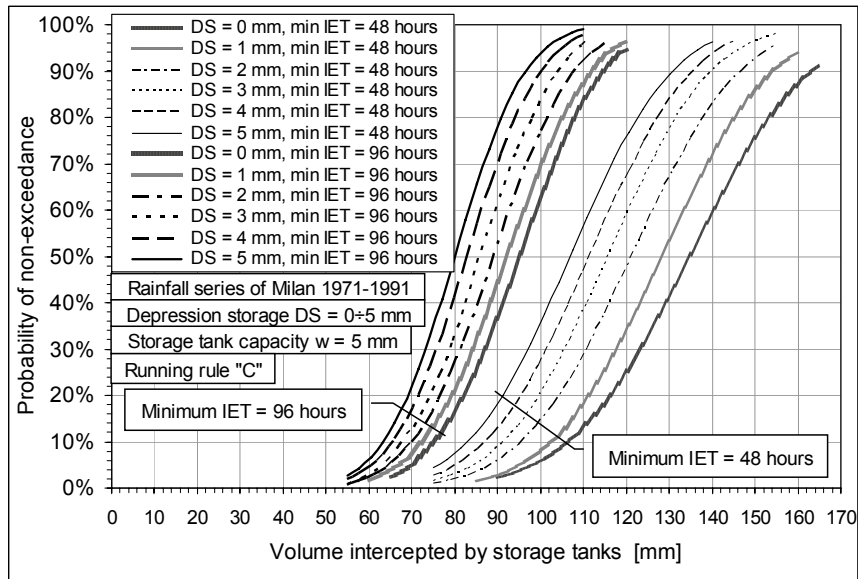


Fig. 4 - Probability of non exceedance for runoff volume intercepted by on-line stormwater tanks having  $w = 5$  mm and run with rules "A" and "C" considering the rainfall series of Milan with minimum IET = 48 hours and 96 hours for depression storage DS varying from 0 to 5 mm

### 3.4 Discussion

First of all, it is confirmed the already well known result that the benefits of increasing the specific storage capacity (in terms of reduction of the volumes delivered to the receiving bodies) are, for each one of the above mentioned rules, less than linear.

Moreover, the intercepted volumes seem to be quite the same for rule "B" and rule "C", while rule "A" achieves an improvement up to 20% in comparison to them, though such a percentage becomes lower when the chosen minimum IET increases.

Finally, the values of the annual intercepted volumes are very well fitted by the Gaussian probability distribution. Hence, for practical purposes, the manager of an integrated water service can use them to evaluate which is the "risk" level ("risk" in the sense of requiring additional costs of treatment for him) to receive a definite additional volume coming from stormwater storage tanks to wastewater treatment plants. In particular, those Gaussian probability distributions are quite steep, therefore having relatively low values of the variation coefficient of the volumes intercepted by tanks.

## 4 CONCLUSION

The results show, as supposed, the relevant influence on the annual intercepted runoff depth given by the running rules of the on-line storage tank, the minimum inter event time (IET), the specific storage capacity  $w$  per impervious catchment area and

the depression storage DS on the catchment surfaces. But, surprisingly, the three different rainfall series examined in the tests seem to yield quite similar outcomes.

In addition, the Gaussian probability distribution has been found to be a good fitting of the annual intercepted runoff depths, allowing an easy forecast of their quantiles for a given probability of non-exceedence (or probability of exceedence). That is a very interesting piece of information for the runners of wastewater treatment plants who are supposed to be in charge of dealing, after rainfall events, with the first foul flush volumes which have been intercepted and stored into the urban stormwater tanks.

Of course such a study is supposed to be extended in the future considering:

- further rainfall series, representing other climates and precipitation regimes;
- off-line stormwater runoff networks of separated systems;
- both on-line and off-line stormwater runoff networks of combined systems;
- water quality modelling.

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## LIST OF REFERENCES

- Adams B.J., Papa F. (2000). *Urban Stormwater Management Planning with Analytical Probabilistic Models*, John Wiley and Sons, ISBN 0-471-33217-8.
- Artina S., Maglionico M. (2005) "Modellazione della rete fognaria di Bologna e la riduzione dell'impatto conseguente all'inserimento di vasche di prima pioggia". *La tutela idraulica e ambientale dei territori antropizzati* (a cura di Paoletti A., Piro P., Sanfilippo U.), Atti dei seminari di Parma (5-6 febbraio 2004) e Cosenza (13-15 dicembre 2004), ed. CSDU, Milano, Italy, ISBN 88-900282-3-8.
- Bacchi B., Balistocchi M., Grossi G. (2006) "Controllo degli scarichi mediante vasche di prima pioggia: verifica di un metodo semprobabilistico". *XXX Convegno Nazionale di Idraulica e Costruzioni Idrauliche IDRA 2006*, Roma, 10-15 settembre 2006, Casa Editrice Università La Sapienza, Roma, Italy.
- Brombach H., Weiß G., Fuchs S. (2004). Combined or separate sewer systems? A critical comparison using a new database on urban runoff pollution, *Novatech 2004*, 5th International Conference, Lyon, France, 6-10 June 2004, ISBN 2-9509337-5-0.
- Ciaponi C., Papiri S., Todeschini S. (2005). Vasche di prima pioggia: analisi critica di possibili modalità di svuotamento. *I Convegno Nazionale di Idraulica Urbana 'Acqua e Città'*, Sant'Agnello (NA), 28-30 settembre 2005 (a cura di Rasulo G., Artina S., Paoletti A., Del Giudice G., Della Morte R.), ed. CSDU, Milano, Italy, ISBN 88-900282-4-6.
- Esser D., Ricard B., Désormeaux R., Blot N., Abran T. (2004). Urban projects and rain water management : integrated approach conditions in the town planning process, *Novatech 2004*, 5th International Conference, Lyon, France, 6-10 June 2004, ISBN 2-9509337-5-0.
- Faram M., Guymer I., Saul A.J. (2004). Assessment of 'modular block' stormwater storage systems, *Novatech 2004*, 5th International Conference, Lyon, France, 6-10 June 2004, ISBN 2-9509337-5-0.
- Mourad M., Bertrand-Krajewski J.L., Chebbo G. (2005). Design of a retention pond: comparison of stormwater quality models with various levels of complexity, *10th International Conference on Urban Drainage*, Copenhagen, Denmark, 21-26 August 2005.
- Paoletti A., Sanfilippo U. (2004) Structural and non-structural measures to reduce pollutants discharged in receiving water bodies, *Novatech 2004*, 5th International Conference, Lyon, France, 6-10 June 2004, ISBN 2-9509337-5-0.