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## **Impact of urban wet-weather discharges to the Vernavola river (Pavia, Italy)**

### **Impact des rejets urbains par temps de pluie dans la rivière Vernavola (Pavia, Italie)**

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#### **RÉSUMÉ**

Cet article présente les résultats d'expériences et de modélisations numériques pour l'estimation des rejets urbains par temps de pluie dans la rivière Vernavola (Pavia, Italie). Tout d'abord, la recherche se concentre sur les rejets urbains par temps de pluie déversés via le réseau d'assainissement dans la rivière Vernavola: un recensement exact des déversoirs d'orage est effectué le long du cours d'eau et de ses branches secondaires; une enquête approfondie est menée sur le fonctionnement des déversoirs d'orage et des stations de pompage connexes. L'étude présente également les principaux résultats des campagnes expérimentales menées par temps de pluie sur la rivière Vernavola lorsque les déversoirs d'orage sont activés. La charge annuelle de polluants par les matières en suspensions est estimée par modélisation des différents systèmes (bassin urbain - réseau d'assainissement) en aval des rejets urbains de temps de pluie au moyen d'un modèle conceptuel fondé sur la théorie du stockage linéaire (Ciaponi et al., 2002). Le volume hydrique et la charge de polluants des rejets par temps de pluie dans la rivière Vernavola sont évalués par rapport à la dimension des déversoirs d'orage et les conditions de fonctionnement des stations de pompage liées. L'article présente aussi une analyse de l'efficacité des déversoirs d'orage et dresse une liste des situations critiques en termes d'impact sur le milieu récepteur. Cette étude représente le point de départ nécessaire pour définir les stratégies de contrôle les plus appropriées dans le but de réduire les rejets de polluants dans la rivière Vernavola.

#### **ABSTRACT**

This paper shows the results of experimental studies and numerical modelling for the evaluation of urban wet-weather discharges to the Vernavola river (Pavia, Italy). First of all, the research focuses on the sewer system that discharges wet-weather flows to the Vernavola river: first of all, it carries out an accurate census of CSOs of this water-course and its secondary branches and secondly, it develops an in-depth investigation on the functioning of CSOs and the related pumping stations. Subsequently, the study presents the main results of experimental campaigns carried out during rainfall events on the Vernavola river when CSOs activate. The annual pollutant load of TSS moved during wet-weather runoff is obtained simulating the systems basin-sewer network upstream CSOs by means of a conceptual model based on the instantaneous unit hydrograph of a single linear reservoir system (Ciaponi et al., 2002). Water volume and pollutant loads discharged into the Vernavola river are estimated from the geometric characteristics of the CSOs and the functioning conditions of the related pumping stations. The memory also furnishes an estimation of CSOs efficacy and a list of critical situations in terms of impact on the receiving water body. This study represents the starting point needed to define the most appropriate control strategies to reduce pollutant load discharged into the Vernavola river.

#### **KEYWORDS**

Combined sewer systems, CSOs, wet-weather discharges, receiving water bodies

## 1 INTRODUCTION

The *Vernavola* river is a small water-course that has its source in the town of *San Genesio ed Uniti* and flows almost entirely in the town of *Pavia*. The *Vernavola* valley presents both historical and geomorphologic – naturalistic peculiarities (Papiri and Todeschini, 2009a), nevertheless, in contrast with its potentialities, different critical situations coexist: strong alteration of the river water quality, low level of ecological functionality, negative pollution impact in the *Ticino* river (Papiri et al., 2009).

The chemical, physical and biological alteration of the *Vernavola* river is due to the diffuse discharges of agriculture and especially to the frequent urban wet-weather discharges. The recent town development has increased significantly the pollutant load discharged in the *Vernavola* through combined sewer overflows (Papiri et al., 2009).

The paper focuses on the sewer system that discharges wet-weather flows into the *Vernavola* river: first of all it carries out an accurate census of CSOs of this water-course and its secondary branches and secondly it develops an in-depth investigation on the operation of CSOs and the related pumping stations.

Subsequently, this study shows the main results of experimental campaigns carried out during rainfall events in order to evaluate the negative impact on the *Vernavola* river induced by CSOs activation.

Annual pollutant load of TSS moved during wet-weather runoff is obtained simulating the systems basin-sewer network upstream CSOs by mean of a conceptual model based on the conceptual scheme of a linear reservoir (Ciaponi et al., 2002).

This study furnishes a detailed census of CSOs, an accurate evaluation of annual pollutant loads related to wet-weather runoff discharged into the *Vernavola* river, an efficacy evaluation of CSOs (in terms of distribution between pollutant mass sent to treatment and that discharged into the river), a list of critical situations in terms of impact on the receiving water body.

The methodological approach adopted for the evaluation of water volumes and pollutant masses sent to treatment and of those discharged into the *Vernavola* river in this complex urban drainage system is a very proper procedure for a global evaluation of the impact related to a plurality of CSOs on a receiving water body.

## 2 URBAN WET-WEATHER DISCHARGES TO THE VERNAVOLA RIVER

Figure 1 shows the course of the *Vernavola* river and the location of the sewer discharges, mainly related to pumping stations that direct wastewater to the treatment plant.

The sewer system refers to a population-equivalent *PE* of about 61,800, about 51,000 civil inhabitants and 10,800 productive inhabitants. The drained surface is about 541 ha, 385 ha impervious surface and 156 ha pervious surface. The census of sewer discharges is carried out by mean of a series of inspections along the course of the *Vernavola* river and its secondary branches (*Vernavolino Mettica* and *Vernavolino*). Table 1 shows the distance between the discharges and the origin of the *Vernavola* river and the main characteristics of the pertinent basins (area and *PE*).

All the discharges are related to CSOs, except for 62, *Spelta* and 70 which are direct discharges of sewer system into the *Vernavola*.

The pumping stations related to CSOs directed to the *Vernavola* river are 21 (see Table 1). There are also three pumping stations (*S13s*, *S8*, *TROVAM*.) inserted in the examined sewer system that don't discharge into the *Vernavola* river.

The majority of the pumping stations and of CSOs receives only wastewater from its pertinent basin, while there are few storm water control devices that collect wastewater both from their pertinent basin and from the upstream sewer system. In this memory, the first devices are defined off-line, while the second ones are called on-line.

## 3 IMPACT OF WET-WEATHER DISCHARGES ON THE VERNAVOLA RIVER

Experimental campaigns on the *Vernavola* river are carried out some days before (after an antecedent dry time of some days) and during some significant storm events (i.e. events that activate CSOs). The



Table 1 Discharges into the Vernavola river and its secondary branches

ID	Location of the sewer discharge	Receiving water body	Distance from the origin [m]	Pertinent basin		Pumping station
				Area [ha]	PE	
<b>SAN GENESIO ED UNITI</b>						
R.L.	Rural area	Vernavola right riverside	205	78,4	3504	R.LAG.
<b>PAVIA</b>						
Polig <sup>#</sup>	Via Poligogna	Miscia River	1824 <sup>*</sup> 4853 <sup>**</sup>	85	12709	POLIG.
31s	Via Montemaino	Vernavola left riverside	1537	19.3	2109	S5
32s	Via Montemaino	Vernavola right riverside	1679	20.6	2472	S6
33s	Via Pavesi	Vernavola left riverside	2116	8.6	998	S6A
30s	Strada Corso	Artificial lake	3355	14.7	1283	S7
44	Via Andreoli	Vernavola right riverside	4597	8.4	1008	
34s	Via Suardi	Vernavola right riverside	4880	1.6	80	S9A
35s	Via Acerbi	Vernavola right riverside	5051	22.6	2712	S9
2s	Via Bordoncina	Vernavolino Mettica	6231 <sup>*</sup> 3381 <sup>**</sup>	2.6	174	BORDON.
3s	Via Torretta	Vernavola left riverside	5523	50.0	4752	S10
60	Via Emilia	Vernavola left riverside	6108	25.8	2580	
62	Via Poma	Vernavolino Mettica	6231 <sup>*</sup> 93 <sup>**</sup>	1.5	150	
4s	Via Fasolo	Vernavolino	8134 <sup>*</sup> 1840 <sup>**</sup>	57.2	5720	S11
26s	Via Fasolo	Vernavolino	8134 <sup>*</sup> 1840 <sup>**</sup>	63.8	6380	S12
Ex61	Via S.to Spirito	Vernavola right riverside	6573	0.9	90	S.TO SP.
Spelta	Via Cascina Spelta	Vernavola right riverside	7075	0.9	90	
69	Via Genova	Vernavolino	8134 <sup>*</sup> 894 <sup>**</sup>	20.1	2010	
6s	Viale Lodi	Vernavola right riverside	7295	4.1	275	S13A
5s	Viale Lodi	Vernavolino	8134 <sup>*</sup> 776 <sup>**</sup>	95.3	6385	S13
70	Via Villa Serafina	Vernavola right riverside	7730	1.1	55	
38s	Molino Tre Mole	Vernavola right riverside	7958	26.6	425	S13B
51	Baldo degli Ubaldi	Vernavolino	9555 <sup>*</sup> 3085 <sup>**</sup>	3.0	240	
9s	S. Pietro in Verzolo	Vernavola right riverside	8405	2.9	232	S15
8s	Via Francana	Pipe, left riverside	12679	13.7	1096	S14
8sbis	Via Francana	Pipe, left riverside	12679	44.6	1413	S1
7	Via Grumello	Vernavola left riverside	13092	11.7	936	
57s	Strada Scagliona	Vernavola left riverside	13331	19.7	624	S2-S3

<sup>#</sup> The Polig discharge never activates because wet-weather flows of the municipalities upstream San Genesio ed Uniti are discharged upstream the pumping station Polig.

<sup>\*</sup> Distance between the origin of the Vernavola and the inlet of the receiver in the Vernavola river

<sup>\*\*</sup> Distance between the discharge into the receiver and the inlet of the receiver in the Vernavola river

Table 2 Index LIM values of monitoring campaigns carried out before and during rainfall event of 30/06/2008. 100-OD (% sat.); BOD<sub>5</sub> (O<sub>2</sub> mg/l); COD (O<sub>2</sub> mg/l); NH<sub>4</sub> (N mg/l); NO<sub>3</sub> (N mg/l); P<sub>tot</sub> (P mg/l); E.coli (UFC/100 ml)

	100-OD	BOD <sub>5</sub>	COD	NH <sub>4</sub>	NO <sub>3</sub>	P <sub>tot</sub>	E.coli	LIM
27/06/2008 – after an antecedent dry period of some days								
V0	39.7	5	9	1.09	1.13	0.39	> 40,000	III
V1	44.2	≤ 2.5	< 5	0.11	2.14	0.28	1,400*	II
V3	29.5	≤ 2.5	< 5	0.09	2.98	0.28	1,100*	II
V4	24.5	≤ 2.5	< 5	0.19	1.93	0.37	5,600	II
V5	17.5	4	7	0.09	1.93	0.29	4,900	III
V6	18.6	≤ 2.5	< 5	0.19	1.99	0.28	12,000	II
V7	14.5	4	8	0.36	1.94	0.32	22,000	III
V8	23.4	≤ 2.5	< 5	0.13	1.75	0.32	25,000	III
1/07/2008 – when CSOs were active								
V0	22.0	13	25	0.47	1.75	0.30	>40,000	V
V1	24.4	8	15	0.17	1.61	0.25	23,100	III
V3	20.6	7	13	0.15	1.81	0.22	22,900	III
V4	21.3	7	13	0.16	1.49	0.26	24,900	III
V5	25.4	10	18	0.12	1.52	0.23	14,000	IV
V6	32.4	9	16	0.21	1.76	0.24	36,900	IV
V7	28.0	10	18	0.19	1.69	0.28	40,000	IV
V8	18.7	11	20	0.63	1.70	0.26	>40,000	IV

\* Low E.coli values are probably due to sampling errors

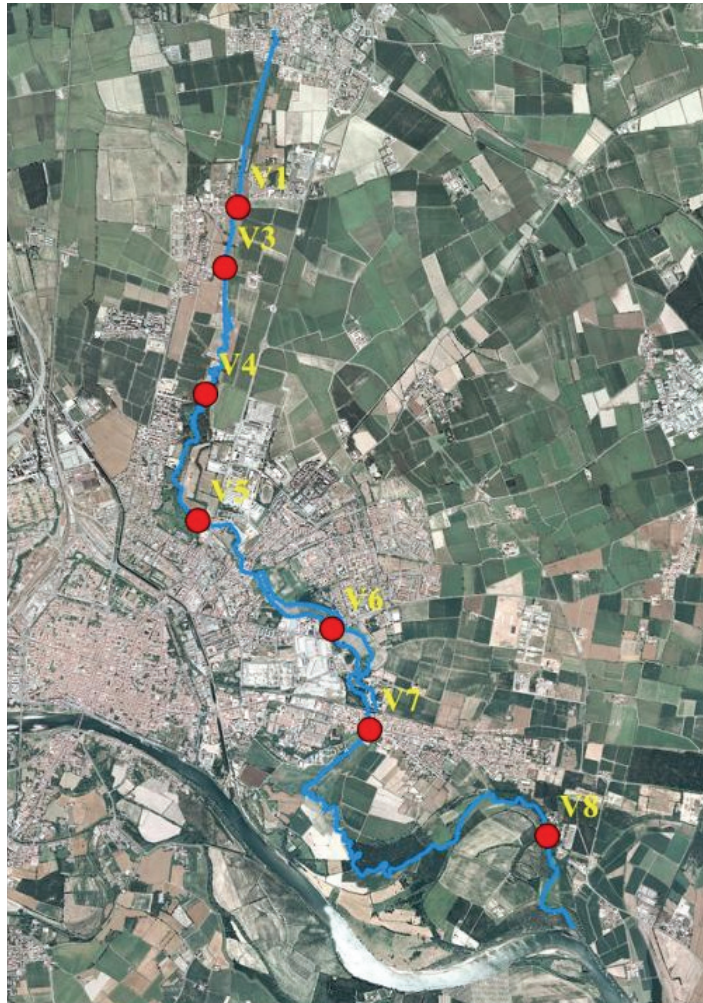


Figure 2 Course of the *Vernavola* river and location of the sampling stations

#### 4 SIMULATION OF URBAN WET-WEATHER POLLUTANT LOAD

Annual water volume and pollutant load of *TSS* moved during wet-weather runoff are obtained simulating the systems basin-sewer network upstream of each point of discharge by mean of a conceptual model based on the instantaneous unit hydrograph of a single linear reservoir system (Ciaponi et al., 2002).

The estimation of hydrographs and *TSS* loadographs is related to storm events occurred in the period 1/08/2006 - 31/07/2007. Experimental hyetographs come from the data recorded at the pluviograph of *Cascina Scala (Pavia)*, located about half course of the *Vernavola* river.

Rainfall events are selected on the basis of an inter event time *IET* between events of 6 hours. In such a way the independence of events is guaranteed at the level of the entire basin of the *Vernavola* (after 6 hours from the end of a storm event, wet-weather runoff runs out both in the sewer system and in the *Vernavola* river). The events with precipitation height less than 2 mm are set apart. The reconstructed hyetographs have a discretization of one minute.

Total precipitation height in the examined period is 795.0 mm, while that of the 51 events selected on the basis of the previous criteria is 716.3 mm: the precipitation height of each event varies in the range 2.1-103.6 mm; maximum rainfall intensity for a minute ranges between 0.01 and 1.99 mm/min; the *IET* between 0.25 and 25.94 days; rainfall duration between 18 and 2050 minutes. The total duration of the selected storm events is 502 hours.

The model adopted was applied to each basin upstream the sewer discharges and upstream the pumping stations *S13s*, *S8* and *TROVAM*. of the sewer system under examination.

Table 3 shows the values of the parameters adopted during the simulations (*IMP*: ratio between the

impervious area and the total area;  $K$ : retention constant;  $\varphi_{imp}$ : ratio between the contributing impervious area and the total impervious area;  $I_{store}$ : initial depression storage;  $ACCU$ : build-up rate of solids;  $DISP$ : spreading coefficient;  $rcoef$  and  $washpo$ : calibration coefficients). These values come from the main characteristics of the examined basins and from previous calibration and validation of the code. The procedure of calibration-validation of the model was applied to two experimental basins located in the *Vernavola* valley: the residential basin of *Cascina Scala* and the production catchment of *Bivio Vela* (Ciaponi et al., 2002; Papiri et al., 2008; Papiri and Todeschini, 2009b).

The parameters related to build-up and wash-off of solids, calibrated for the two experimental basins, are also adopted for the other basins under examination because they are very close and have similar characteristics.

Actually, wet-weather samples are collected by a refrigerated automatic grab sampler equipped with 24 bottles in the stretch downstream of the *Vernavola* river. In this section also flow data are recorded. The collected data and the analysis of samples will be useful for the global validation of the presented simulations.

Table 3 Values of the parameters adopted for the simulation of the basins under examination

	$IMP$	$K$ [min]	$\varphi_{imp}$	$I_{store}$ [mm]	$ACCU$ [kg/ha/d]	$DISP$ [d <sup>-1</sup> ]	$rcoef$ [min <sup>-1</sup> ]	$washpo$
Residential basins	0.5÷0.65	3÷16	0.80	2	18	0.3	0.2	1.2
Production basins	0.7÷0.85	10÷14	0.85	2	11	0.3	0.2	1.2

Being the sewer a combined system, the contribution of waste water was added to the hydrographs and loadographs obtained from the simulations. A water supply of 250 l/(PE d), a TSS production of 90 g/(PE d) in residential areas and of 36 g/(PE d) in production areas have been adopted. Also these values come from experimental campaigns on the *Cascina Scala* and *Bivio Vela* basins of the *Vernavola* Valley.

Volumes and pollutant masses sent to waste water treatment plant *WWTP* and those discharged into the *Vernavola* river are obtained with the following procedure:

- direct discharges (62, *Spelta* and 70): volume and pollutant mass to the *Vernavola* river are evaluated respectively as integral of water and mass flow coming from the simulation. Obviously, volume and pollutant mass to *WWTP* are equal to zero.
- CSOs off-line - CSOs related to pumping stations off-line: hydrographs and loadographs of the basin acting on each CSO came from the simulation. Design and functioning characteristics of CSOs and pumping stations furnish wet-weather volume and pollutant mass sent to *WWTP* and, consequently, those discharged to the *Vernavola* river.
- CSOs on-line - CSOs related to pumping stations on-line: the hydrographs and loadographs of the basin acting directly on the CSO are added to the contributions of water and pollution mass of the sewer network upstream, taking into account the time of transfer. Subsequently, design and functioning characteristics of CSOs and pumping stations furnish wet-weather volume and pollutant mass sent to *WWTP* and, consequently, those discharged to the *Vernavola* river. Figure 3 shows an example of this procedure for storm event of 12/08/2006 and on-line pumping station *S12*.

For each discharge, Figure 4 shows annual water volume and mass of TSS to the *Vernavola* river. Annual load of TSS discharged is equal to 184,553 kg. This value represents the 8% of the annual mass passing in the combined sewer system and the 36% of annual mass related to wet-weather runoff. Figure 5 shows the contribution (%) of each discharge to the annual volume and mass of TSS flowing into the *Vernavola* river. The CSOs related to pumping stations *S12*, *S13* and *R.LAGH*. are those which contribute much more to the pollution of the receiving water body.

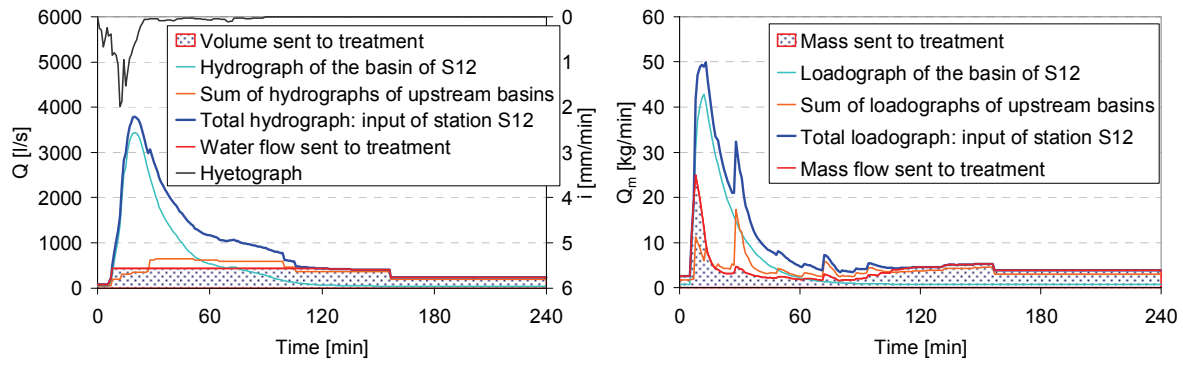


Figure 3 Example of the procedure adopted for the evaluation of water volume and pollutant mass sent to treatment: on-line pumping station S12 and storm event of 12/08/2006

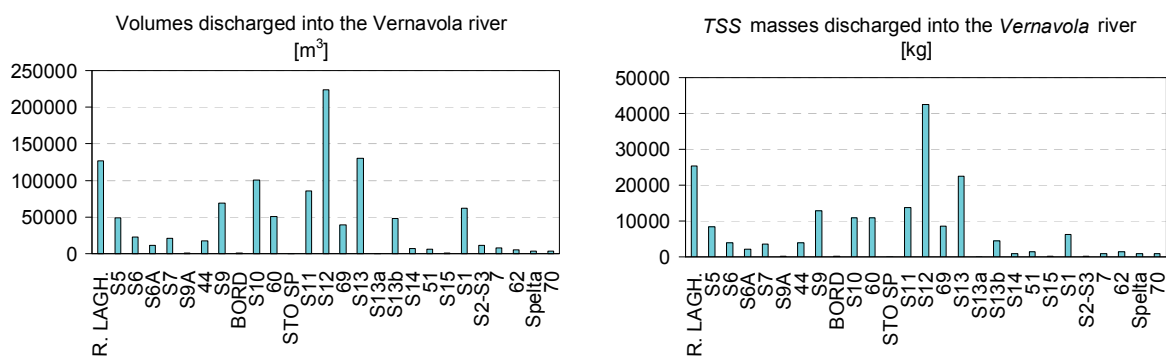


Figure 4 Annual water volumes and TSS masses discharged into the Vernavola river

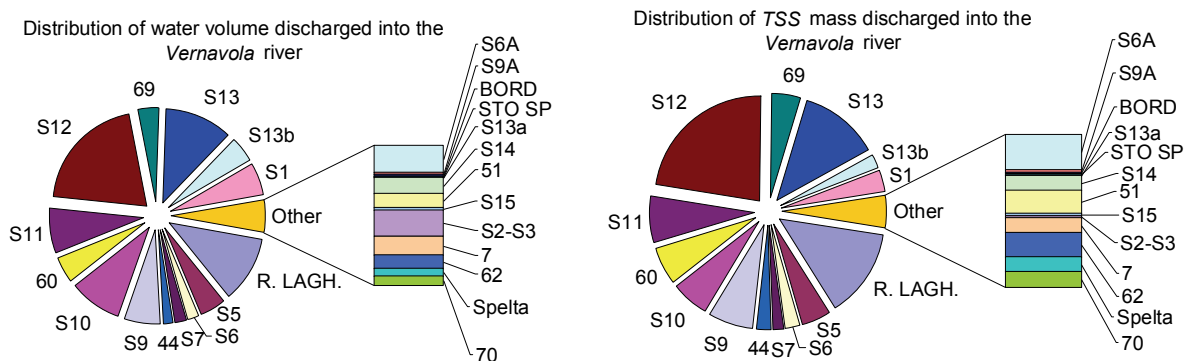


Figure 5 Contribution (%) of each discharge to the total volume and mass of TSS to the Vernavola river

## 5 CONCLUSIONS

This research accurately describes the negative impact induced by urban wet-weather sewer discharges on the Vernavola river:

- Experimental campaigns show that during significant storm events the quality of this receiving water body suffers a significant worsening in all the sampling stations than in dry time. LIM Index passes from a “satisfactory-good” to a “satisfactory-poor” quality condition, even “very poor” quality for the sampling station V0. COD, BOD<sub>5</sub> and E.coli assume very high values due to the discharges through CSOs of the organic matter inside sewer deposits. Worse quality characteristics are also due to the suspension of organic sediment at the bottom of the river.

- Simulations of storm events occurred in the period 1/08/2006 - 31/07/2007 show that annual load of TSS discharged into the *Vernavola* river is equal to 184,553 kg. This value represents the 8% of the annual mass passing in the combined sewer system and the 36% of annual mass related to wet-weather runoff.

These results indicate that a careful management of urban wet-weather discharges would be of great relevance in defining the quality of this surface water body.

This study also furnishes the knowledge priorities for decision-makers in order to define the most appropriate strategies aiming at reducing pollutant loads discharged into the *Vernavola* river:

- estimation of the efficacy of CSOs and related pumping stations (in terms of distribution between pollutant mass sent to treatment and that discharged into the river)
- list of critical situations in terms of impact on the receiving water body: CSOs related to pumping stations *S12*, *S13* and *R.LAGH*. are those which contribute much more to the pollution of the *Vernavola* river.

The methodological approach adopted for this complex urban drainage system is a very proper procedure for a global evaluation of the impact related to a plurality of CSOs on a single receiving water body.

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## LIST OF REFERENCES

- Ciaponi C., Mutti M., Papiri S. (2002). *A conceptual model for the estimation on loadographs in sewer networks during meteorological events*. Proceedings of the 2<sup>nd</sup> International Conference "New Trends in Water and Environmental Engineering", Capri (Italy), June, 24-28, CSDU Milano, ISBN: 88-900282-2-X.
- Papiri S., Ciaponi C., Todeschini S. (2008). *Il bacino urbano sperimentale di Cascina Scala (Pavia). Piogge portate e qualità dei deflussi in fognatura nel periodo 1987-2006*. Aracne Editrice, Roma, ISBN: 978-88-548-2132-3.
- Papiri S., Pesci I., Sconfiotti R., Todeschini S. (2009). *La qualità della roggia Vernavola in base a indicatori biologici e chimici*, Acqua e città: III Convegno Nazionale di Idraulica Urbana, Milano, 6-9 ottobre 2009, CSDU Milano.
- Papiri S., Todeschini S. (2009a), *La roggia Vernavola e il suo Parco: excursus storico*, Acqua e Città: III Convegno Nazionale di Idraulica Urbana, Milano, 6-9 ottobre 2009, Edizioni CSDU Milano.
- Papiri S., Todeschini S. (2009b), *Pollution in stormwater runoff in a production catchment: monitoring campaign and modelling*. Theoretical and experimental characterization of the impact on receiving streams due to conservative and non-conservative pollutants transported by urban run-off waters, CSDU, Milan, ISBN: 978-88-903223-1-0.