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Emission standards versus immission standards for assessing the impact of urban drainage on ephemeral receiving water bodies

Gabriele Freni, Giorgio Mannina and Gaspare Viviani

ABSTRACT

In the past, emission standard indicators have been adopted by environmental regulation authorities in order to preserve the quality of a receiving water body. Such indicators are based on the frequency or magnitude of a polluted discharge that may be continuous or intermittent. In order to properly maintain the quality of receiving waters, the Water Framework Directive, following the basic ideas of British Urban Pollution Manual, has been established. The Directive has overtaken the emission-standard concept, substituting it with the stream-standard concept that fixes discharge limits for each polluting substance depending on the self-depurative characteristics of receiving waters. Stream-standard assessment requires the deployment of measurement campaigns that can be very expensive; furthermore, the measurement campaigns are usually not able to provide a link between the receiving water quality and the polluting sources. Therefore, it would be very useful to find a correlation between the quality status of the natural waters and the emission-based indicators. Thus, this study is aimed to finding a possible connection between the receiving water quality indicators drawn by environmental regulation authorities and emission-based indicators while considering both continuous (i.e. from the wastewater treatment plants) and intermittent pollution discharges (mainly from combined sewer overflows). Such research has been carried out by means of long-term analysis adopting a holistic modelling approach. The different parts of the integrated urban drainage system were modelled by a parsimonious integrated model. The analysis was applied to an ephemeral river bounding Bologna (Italy). The study concluded that the correlation between receiving water quality and polluting emissions cannot be generally stated. Nevertheless, specific analyses on polluting emissions were pointed out in the study highlighting cause—effect link between polluting sources and receiving water quality.

Key words | urban drainage integrated modelling, Water Framework Directive, water quality management, water quality monitoring

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INTRODUCTION

Until the last two decades, urban drainage systems were analysed in terms of their hydraulic aspects, especially for estimations of the damage caused by surcharge events. Recently, awareness about the environmental impacts of urban drainage systems has been growing and the evaluation of the receiving water body (RWB) quality has become a fundamental issue. Today, a challenge is maintaining a high quality aquatic environment and preventing the detrimental effects of both continuous (i.e. from the wastewater treatment plant–WWTP) and intermittent pollution discharges (mainly from combined sewer overflows–CSOs).

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Regarding the environmental preservation of natural water bodies, a change has been made in Europe in 2000 via the Water Framework Directive (WFD) that, focusing on the ecological status of the river, requires the adoption of the stream-standard approach to river water quality analysis, as opposed to the old emission-standard approach. This new approach has raised the importance of an integrated design and the management of urban drainage systems (Chave 2001). Some years before, a similar process was carried out in North America according to the regulations set by the National Pollutant Discharge Elimination System (NPDES) that defines stringent emission standards designed to meet stream quality standards (Diller 1995). The impact of urban pollution on the final recipient can only be evaluated based on the recipient's sensitivity to the pollutants and its self-cleaning capacity. This type of evaluation is more complicated when both dry and wet weather discharges to the RWB are considered; dry weather pollution is usually characterised by continuous and scarcely variable loads, while wet weather discharges are usually intermittent and the relevant loads are to the RWB in a short period of time.

The WFD defines standards for preserving receiving waters, but technical and analytical difficulties are present in the definitions of parameters used for identifying the impacts of polluting: some parameters, such as the discharged peak concentration or polluting spill frequency, may be misleading (Lau *et al.* 2002), while the evaluation of more appropriate indicators such as pollutant concentrations in the RWB can lead to complex computations. Several approaches have been presented in literature in the past decades that can be divided into two main classes:

- emission-standards: these define the pollutant concentrations, loads and discharge frequencies that represent thresholds that need to be observed in order to maintain the environmental status of the RWB;
- stream-standards: these define the polluting concentrations and persistence times that can compromise the environmental status of the RWB if their frequency is higher than a specified threshold.

The evident difference between the two approaches is that the former does not consider the effective characteristics of the RWB as well as its self-depurative capacity. Furthermore, emission-standards are based on variables that can be measured or simulated for a given urban drainage level without directly analysing the RWB system.

On the other hand, the stream-standards use the RWB characteristics to fix receiver-based water quality standards while considering both the environmental relevance of the water body and its self-depurative capacity.

Both approaches may take advantage from the application of modelling tools that can be used for scenario analysis or long term simulation after their calibration and validation over field gathered data. From a modelling point of view, both approaches are more efficient if connected with a long-term analysis, but stream-standards implicitly require simulations of the propagation of pollution in the RWB and the treatment efficiency of the WWTP; this requires the use of integrated models and complex monitoring campaigns for proper calibration.

Several studies have indicated that it is difficult to apply stream-standards, especially in basins characterised by numerous sources of pollution (Quilbè & Rousseau 2007). The high nonlinearity of the processes active in urban areas and in the river requires that the processes be simulated with the highest possible resolution; this aspect makes the definition of pollution sources harder (Børgesen *et al.* 2001; Haberlandt *et al.* 2002; Uhlenbrook *et al.* 2003). Several authors proposed the adoption of more detailed monitoring campaigns (involving several measuring points) in order to track down the sources of contamination (for example, see: Shanahan *et al.* 1998; Van Griensven & Bauwens 2001, 2003; Karamouz *et al.* 2008).

Another important issue of the adoption of stream-standard approaches is related to the use of complex numerical modelling techniques that are able to represent the whole system but require long calibration procedures and high computational capabilities. In this field, several studies have suggested the adoption of simplified integrated numerical models that are able to reproduce the different parts of the whole urban integrated system, including the sewer system (SS), wastewater treatment plant (WWTP) and RWB, in a reliable way for both dry and wet weather conditions (Rauch & Harremoës 1996; Rauch *et al.* 2002; Schmitt & Huber 2006); at the same time, the models should consume the smallest amount of computational resources as possible.

Simplified integrated approaches focus on a reduced number of processes for which reliable information is more frequently available but, on the other hand, the processes parameters are more site-specific and models require intensive calibration and the uncertainty in the results can be large (Mannina *et al.* 2006; Willems 2006; Freni *et al.* 2008*a*–*c*, 2009). However, these types of models have a shorter calculation time, which may be advantageous when long term simulations are necessary (Vaes & Berlamont 1999; Erbe *et al.* 2002; Willems 2006). Even if simplified integrated models can reduce the computational efforts required for the stream-standard approach, the monitoring efforts needed for stream-standards quantification sometimes remain high, preventing an assessment of the quality of the RWB.

It would be very useful to gain information about the status of a RWB from emission-based indicators, i.e. establish a direct connection between emissions and the RWB quality (immission). Such a connection would reduce monitoring costs, as it would only be necessary to focus on the urban drainage system. To this end, previous studies revealed that the mean annual overflow volume can be a good indicator for describing the RWB quality (Engelhard *et al.* 2008). On the other hand, these studies pointed out that the number of overflows per year as well as the acute impact measured by the oxygen depletion and ammonia concentration cannot be a reliable indicator for the RWB quality. Therefore, for these latter cases, specific analysis involving RWB measurement campaigns had to be carried out. Other studies indicate that the overflow frequency can be used to determine compliance with the DO (dissolved oxygen) and BOD standards; both the overflow frequency and overflow volume can be used as indicators of the RWB impact (Lau *et al.* 2002). Several studies in this field have reported the high nonlinearity of water quality processes in the RWB and the difficulty of simply relating emission standards to the RWB quality (Van Griensven & Bauwens 2001, 2003). Such studies were focused on perennial rivers in which the RWB processes as well as its quality state were not controlled by pollution emissions; better results may be obtained in ephemeral rivers. Ephemeral rivers are characterised by a variable hydraulic regime with discharges usually ranging from a few liters per second during the dry summer season up to several cubic metres per second during the wet weather season. Under such conditions, the RWB quality is dominated by point discharges and a correlation between the river quality and emissions level may be easier to quantify (Freni *et al.* 2008*a*).

The main goal of this paper is to formulate a connection between the RWB quality indicators determined by environmental regulations (i.e. WFD or Urban Pollution Manual–UPM) and emission-based indicators considering both continuous and intermittent discharges of pollution. In this study, both classical emission standards and new indicators are considered in order to establish a cause-effect relationship between the RWB quality and sources of pollution. This study focuses on ephemeral rivers because this type of river is mainly affected by urban point discharges and therefore a correlation between emissions standards and stream quality standards may be easier to determine. In order to achieve such objectives, a parsimonious bespoke integrated model, developed during previous studies (Mannina *et al.* 2004, Mannina 2005), was employed to analyse the relationship between the SS, WWTP and RWB. The proposed analysis technique is applied to a monitored urbanised catchment in Bologna (Italy).

MODELS AND METHODS

The adopted integrated model

As discussed above, a previously developed quality-quantity integrated urban drainage model has been employed. For sake of conciseness, this paper will only discuss the model's structure; refer to the literature for further details (Mannina *et al.* 2004; Mannina 2005). The model is able to estimate the interactions between different systems (SS, WWTP and RWB) and the changes to the quality of the RWB induced by urban stormwater. Such a system is made up of three sub-models (Figure 1):

- the rainfall-runoff and flow propagation sub-model, which is able to evaluate the quality-quantity features of SS outflows;
- the WWTP sub-model, which is representative of the treatment processes;
- the RWB sub-model that simulates the dynamics of pollution inside a river.

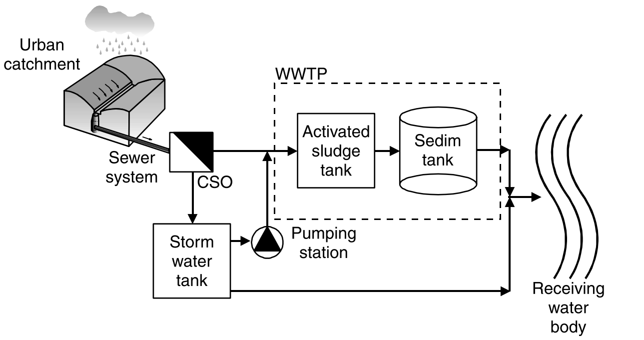

Figure 1 | Schematic of the integrated urban drainage model and its interconnections.

The first sub-model, which reproduces the physical phenomena that take place both in the catchments and in the sewers, determines the hydrograph and pollutograph in the sewer. This sub-model is divided into two connected parts: a hydrological-hydraulic module that calculates the hydrographs at the inlet and the outfall of a sewer system, and a water quality module that calculates the pollutographs at the outfall for different pollutants via measurements of the TSS, BOD and COD. The hydrological-hydraulic module evaluates the net rainfall from the measured hyetograph using a loss function that accounts for the surface storage and soil infiltration. From the net rainfall, the model simulates the net rainfall-runoff transformation process and the flow propagation with a cascade of one linear reservoir and a channel (representing the catchment) and a linear reservoir (representing the sewer network). The solid transfer module reproduces the build-up and wash-off of pollutants from the catchment and the propagation of solids in the sewer network while also considering their sedimentation and re-suspension (Mannina 2005; Freni *et al.* 2008*c*).

The WWTP sub-model analyses a WWTP during both dry and wet periods. The WWTP inflow is computed by considering the presence of a combined storm overflow (CSO) device and its efficiency. The WWTP sub-model simulates the behaviour of the part of the plant composed of an activated sludge tank and a secondary sedimentation tank. In the activated sludge tank model, the equations derived from Monod's theory are used in order to reproduce the BOD removal (Metcalf & Eddy 1991). The sedimentation tank is simulated using the solid flux theory according to the model proposed by Takács *et al.* (1991). This model evaluates the WWTP under dynamic conditions such as in the case of a storm event. In particular, the increases to the flow rates and total suspended solids (TSS) cause a reduction in treatment efficiency at both the activated sludge tank and the sedimentation tank. This effect can cause TSS overflow and discharging in the RWB.

The third sub-model assesses the RWB. A simplified form of the Saint-Venant Equation (kinematic wave) is used for the quantity module and the water de-oxygenation and re-oxygenation phenomena are simulated via the advection-dispersion equation with terms for the sedimentation and biodegradation of the BOD and oxygen depletion; this approach is able to evaluate the effects of stormwater on the RWB, both at a single event scale and for a long-term simulation. There are two main pollutant sources that degrade the quality of the RWB: WWTP discharges and CSOs. This sub-model simulates the effects of CSO control devices during the temporary accumulation of stormwater during a rainfall event.

The panel of environmental impact indicators

Some of the most important contributions to stream-standard approaches have been given by UPM (Foundation for Water Research 1998), which defines the concentration and duration thresholds and frequencies that should not be breached; these thresholds are called the Fundamental Intermittent Standards (FISs). The FISs are specified for different ecosystems and pollutants (Zabel *et al.* 2001), and they should not be violated more frequently than the specified value.

As discussed previously, this study considers a long-term analysis; in particular, some of the UPM indicators have been applied to the RWB. The thresholds for the BOD concentrations have been computed in previous studies according to the river's characteristics and the minimum allowed return period (Artina *et al.* 1999; Maglionico 1999):

- BOD concentration higher than 40 mg/l for 5 hours with a return interval of 1 month and DO concentration lower than 4 mg/l for 1 hour with a return interval of 1 month;
- BOD concentration higher than 48 mg/l for 5.5 hours with a return interval of 3 months and DO concentration lower than 3.5 mg/l for 1 hour with a return interval of 3 months;

- BOD concentration higher than 56 mg/l for 6 hours with a return interval of 1 year and DO concentration lower than 3 mg/l for 1 hour with a return interval of 1 year.

Concerning the emission standards the following indicators have been considered: CSO peak flow, CSO volume, CSO peak BOD concentration and load.

CASE STUDY

The method described above was applied to a semi-hypothetic case study, i.e. a case obtained by the integration of real and hypothetical sub-systems (Rauch & Harremoës 1996; Fu *et al.* 2009). This approach was used in literature for testing models and procedures when a complete case study was not available (Schütze *et al.* 1999). In this specific analysis, the SS and the RWB belongs to the Savena experimental catchment (Bologna, Italy). Due to the fact that the outlet of the Bologna's WWTP is not tributary to the Savena river, an hypothetical WWTP was designed to treat the wastewater coming from the SS in order to evaluate the effect of both continuous and intermittent pollutant discharges.. The sewer system and the river studied in this work contains part of the sewer network of Bologna, which is also studied in the European Union research project INNOVATION 10340I (Artina *et al.* 1999). The Savena is a rural ephemeral river that passes through a number of small towns before entering the southern neighbourhood of Bologna. The catchment area of the Savena, located at the downstream boundary of the studied river reach, is nearly 160 km^2. The river is characterised by a highly variable hydraulic regime and a discharge usually ranging from few litres per second during the dry summer season up to several cubic metres per second during the wet season.

The studied river reach was about 6 km long, and receives the discharges of 6 CSO devices from the Bologna sewer network and 10 from the San Lazzaro sewer systems, a small centre in the surrounding area of Bologna (Figure 2). The CSO devices are all side-weirs without any specific screen for removing floating pollutants. The 10 CSO devices connected to San Lazzaro sewer system did not provide any relevant discharge during the monitoring period and, for this reason, they were neglected from the study. Similarly San Lazzaro sewer is connected to a WWTP that is outside the analysed catchment so the whole sewer network was neglected in the study. The monitoring campaign revealed also that on the Bologna side of the river, only the most downstream CSO device (CSO device No. 6) provided relevant discharges so it was

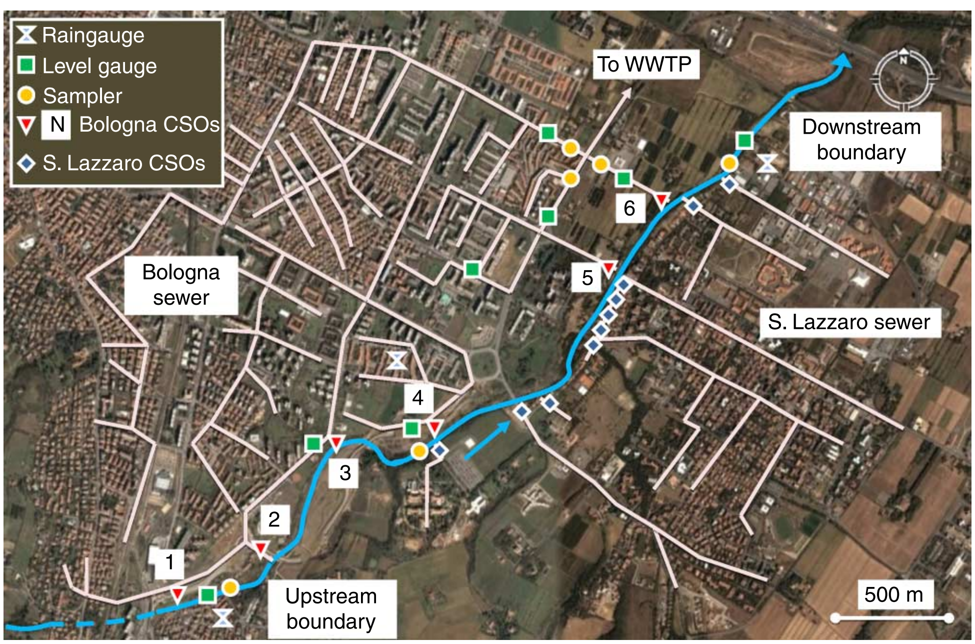

Figure 2 | Savena case study (Bologna—Italy).

the only one included in the modelling application. The sewer network is part of a combined system that serves the whole city of Bologna, which can be considered as hydraulically divided into many independent catchments that are all connected to a WWTP. The whole city of Bologna has about 500,000 inhabitants and an equivalent population of about 800,000 inhabitants. Only the part of this catchment that affects the reach of the Savena river studied here has been taken into account. This part of Bologna has an area of more than 450 ha with an impervious percentage of about 66% and about 60,000 inhabitants.

Concerning the SS and RWB sub- models, they were calibrated using data collected from the INNOVATION DGXIII European Project during the period from December 1997 to July 1999, even though this study's long-term analysis is based on 5 years of continuous rainfall registered at the Fossolo raingauge inside the catchment.

The WWTP was designed to handle an average dry weather flow (DWF) of about 35 l/s (equal to the measured DWF in the monitored SS) and a maximum wet weather flow equal to five times the DWF. The WWTP was made up of an activated sludge tank and a final circular settler. The kinetic parameters for WWTP design have been selected according to technical literature (Henze *et al.* 2000).

METHODOLOGY APPLICATION

The methodology application was based on long term continuous simulation of the system by an integrated urban drainage model, calibrated and validated by means of several monitored rainfall events. The simulation covered a period of 5 years. The rainfall data were collected with tipping bucket raingauges with volumes equivalent to 0.1 mm of rainfall and data loggers with a maximum resolution of 1 s. The main characteristics of the rain data are summarised in Table 1. The integrated model was calibrated during single events: upstream sub-model parameters were calibrated first and then kept constant during the calibration of the downstream parameters. Analogously, the water quantity modules were calibrated before the water quality modules. The system geometry was considered to be exactly known and unaffected by errors. A description of the model's parameters as well as the model's calibration and validation are discussed in detail in previous studies (Mannina 2005; Freni *et al.* 2008*a*). Calibration results were satisfactory allowing to use the model as a prediction tool in the presented scenario analysis. The sub-systems were modelled step-wise by using the output of one sub-system as an input of the following one. In Figures 3 and 4, the hydrographs and pollutographs obtained from the long-term simulation are shown. In particular, Figure 3a and b show, respectively, the WWTP outflow and CSO discharge during the simulated period; and the corresponding BOD concentrations are shown in Figures 4a and b. In addition, Figures 3c and 4c show the RWB flow and BOB and DO concentrations in the selected cross-section.

In order to determine the correlation between the RWB quality stream-standard indicators, as drawn from the UPM and expressed as FIS, and the emissions based indicators, the study was divided in three different phases:

- first, a comparison between the stream-standards (FIS) and the most common emission-standards (CSO peak flow, CSO peak BOD concentration and load, etc.) was carried out;
- second, the relationships between the urban drainage emissions and RWB quality level were analysed considering the application of the FIS criteria not only to the RWB but also to the intermittent outflows;

Table 1 | Adopted rainfall series characteristics

	1994	1995	1996	1997	1998
Rainfall depth [mm]	312	614	701	403	802
No. Events (Vrain > 2 mm)	37	46	41	35	49
Average ADWP [days]	9.86	7.93	8.90	10.43	7.45
Average rainfall intensity [mm/h]	6.45	8.52	5.25	7.36	6.62
Maximum 5 min rainfall intensity [mm/h]	37.8	42.2	57.8	36.5	42.8

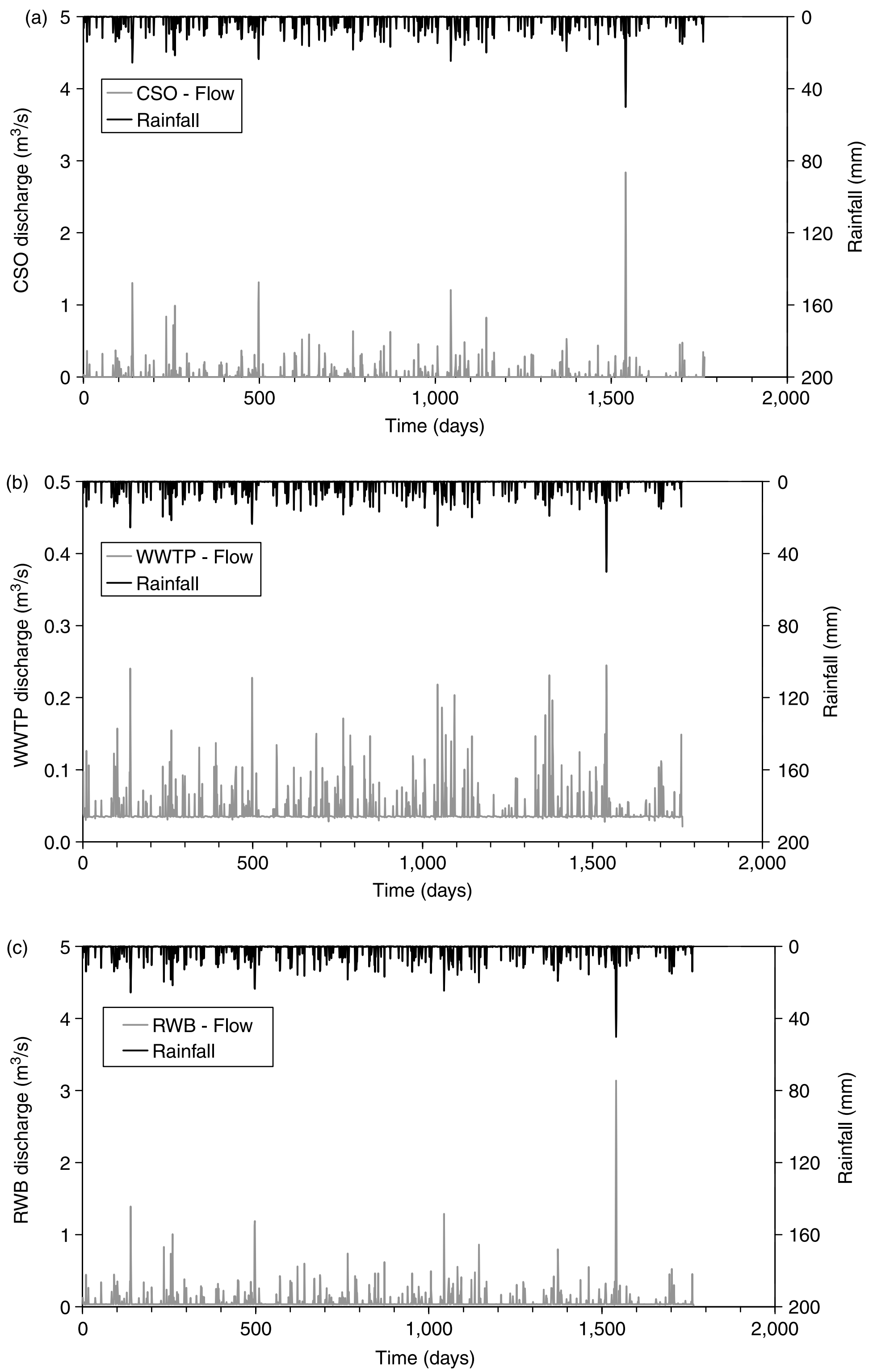

Figure 3 | Results of the long term simulation in terms of (a) the WWTP outflow, (b) CSO discharge, and (c) the RWB flow.

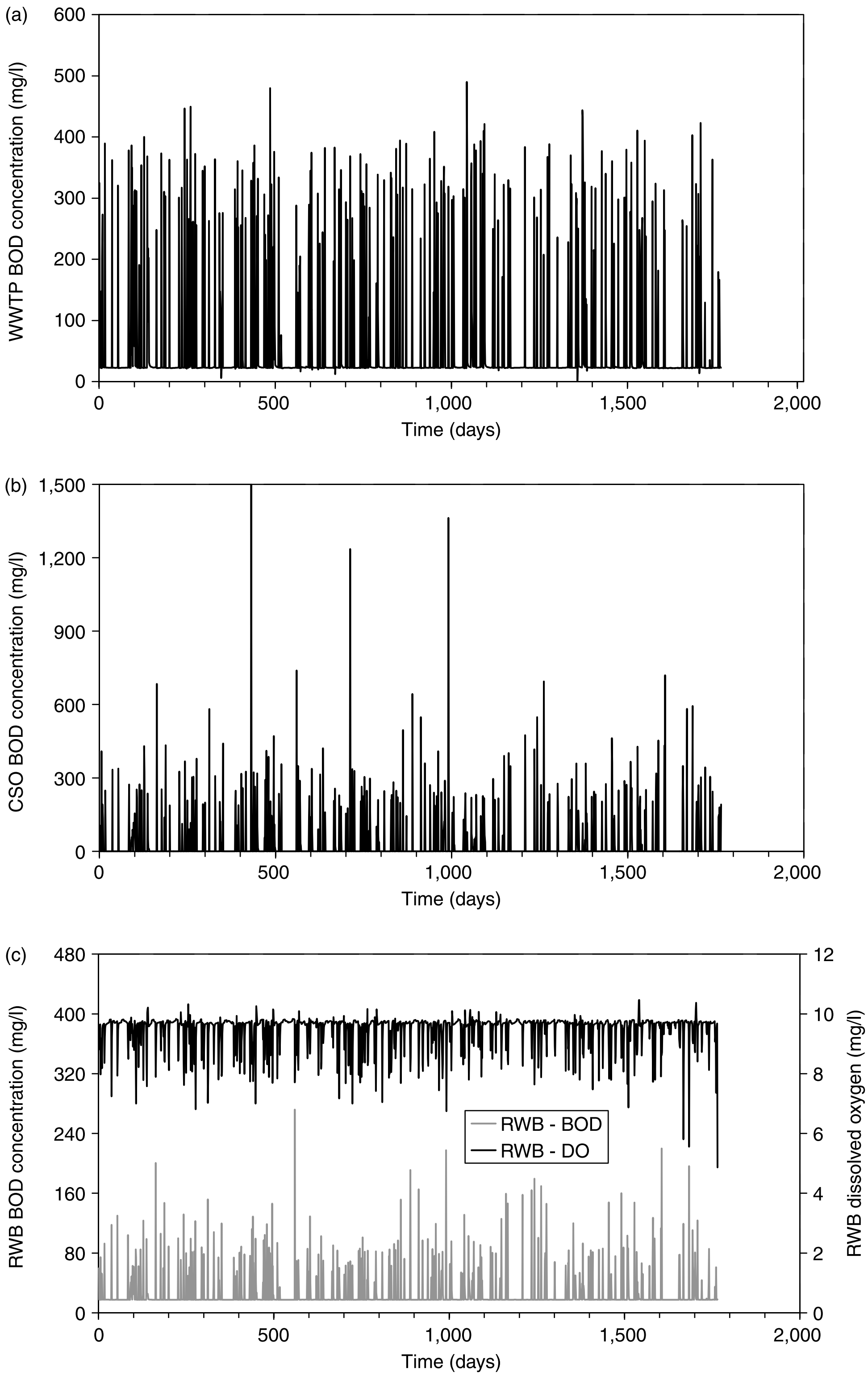

Figure 4 | Results of the long term simulation in terms of (a) the BOD WWTP outflow, (b) BOD CSO discharge, and (c) DO and BOD in the RWB.

- finally, the frequency of the FIS violations on the urban drainage emissions and the RWB water quality were analysed.

RESULTS AND DISCUSSION

Considering the limits drawn by the UPM discussed in the previous paragraph, a possible correlation between stream standard and emission standards was surveyed. In particular, in Figure 5, the persistence of the RWB BOD concentration over the UPM limits has been compared with some emission-standards. The following conclusions can be drawn from Figure 5:

- the stream-standards and emission-standards are generally uncorrelated;
- there is no specific trend in the graphs that demonstrates a significant dependency of the RWB BOD concentration persistence on one specific emission variable;
- A slight correlation can be found for the BOD discharged mass (Figure 5b), but it is not sufficient for practical applications.

Such considerations may be partially explainable by the fact that higher persistence of BOD in the RWB is provided by long events characterised by low peak concentrations, medium-low peak discharge and large CSO volumes and discharged polluting masses (Figure 5). On the contrary, small peaky events (high CSO discharges and BOD concentrations) do not usually cause high persistence because they are mitigated by RWB dilution effects depending on the discharge contribution of the upstream natural catchment. For such reasons, the BOD emission peak and total discharged mass are not representative of the responses of all of the pollutographs of the urban drainage system.

As shown by Figure 5, there is high scattering of points, i.e. the same stream standard value may correspond to emission stream standard values. This is due to the fact that the impact of the polluting discharges on the RWB depends on the combination of natural dilution and timing, shape and overall mass of the contributing pollutograph. This latter is moreover dependent on the behaviour of the WWTP and of the CSO devices.

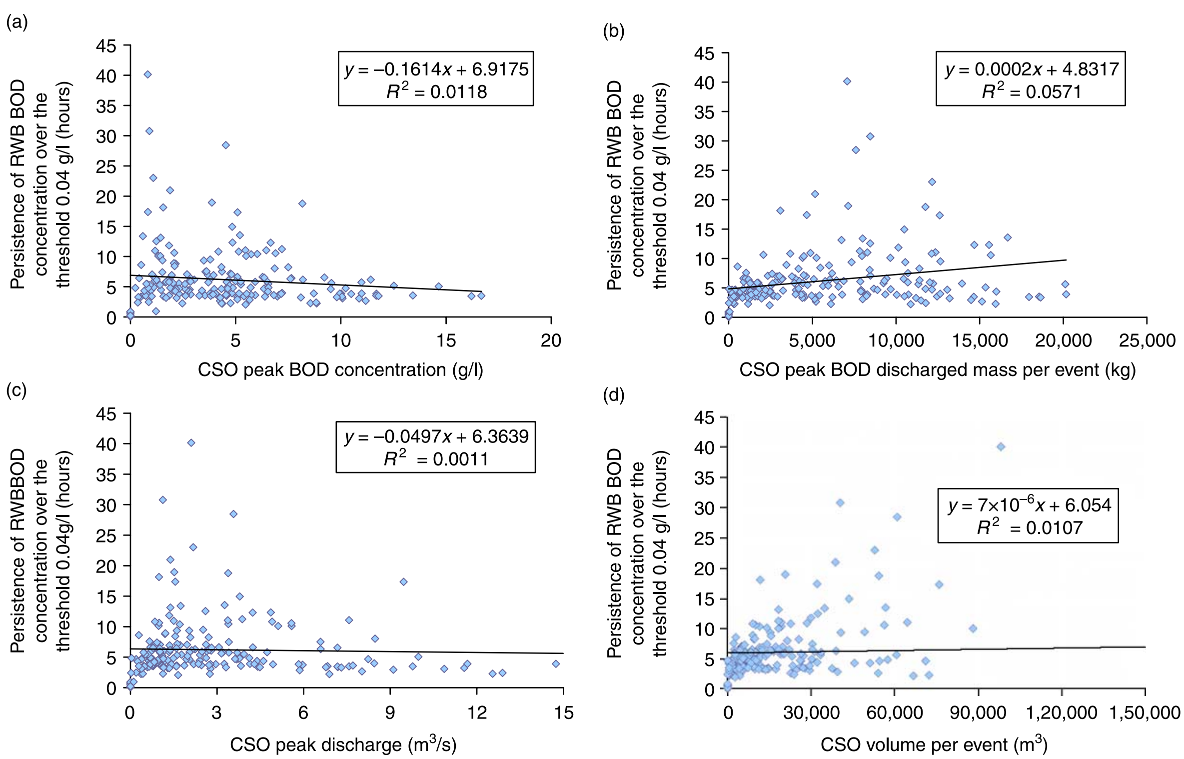

Figure 5 | A comparison between RWB BOD stream-standards and emission-standards is shown.

In addition, the polluting load discharged by the urban drainage system depends on several processes that are non-linear (build-up, wash-off, sewer sediment deposition and erosion, etc.). These processes may result in a temporal delay of the polluting loads' propagations to the RWB and they may affect the BOD peak concentration discharged to the RWB, resulting in different impacts on the RWB water quality. The impact of each non–linear process cannot be easily singled out, thus the polluting impact on the RWB cannot be well represented by usual emission variables such as peak concentrations or loads.

Analogous results have been found for nutrients, as they are largely dependent on WWTP behaviour and they are characterised by kinetics that are strictly nonlinear and dependent on the BOD availability (Engelhard *et al.* 2008).

After verifying the unreliability of correlations between RWB quality indices and emitted polluting concentrations and masses, the study focused on more complex emission variables trying to incorporate the complexity of the non-linear processes described above. Using the results obtained in this study, a potential correlation was explored considering the application of the FIS criteria not only to the RWB but also to the intermittent outflow (second phase). In particular, the persistence of the BOD concentration over the UPM thresholds was analysed for the CSO discharge and it was compared with the same variable computed for the RWB (Figure 6). A correlation was found, at least statistically ($R^2 = 0.7$), as demonstrated by linear trends shown in Figure 6. The linear trend was obtained by minimising the root mean square error. Figure 6 shows an intercept greater than zero, which is justified considering that the RWB quality is dominated by the WWTP emissions for small rainfall events.

Some inaccuracy is still present in the graphs and the average errors between the simulation results and the linear interpolation are equal to 31% (Figure 6a) and 24% (Figure 6b). This error could be significant in practical applications, suggesting that RWB simulation models should not be replaced by simpler urban drainage models.

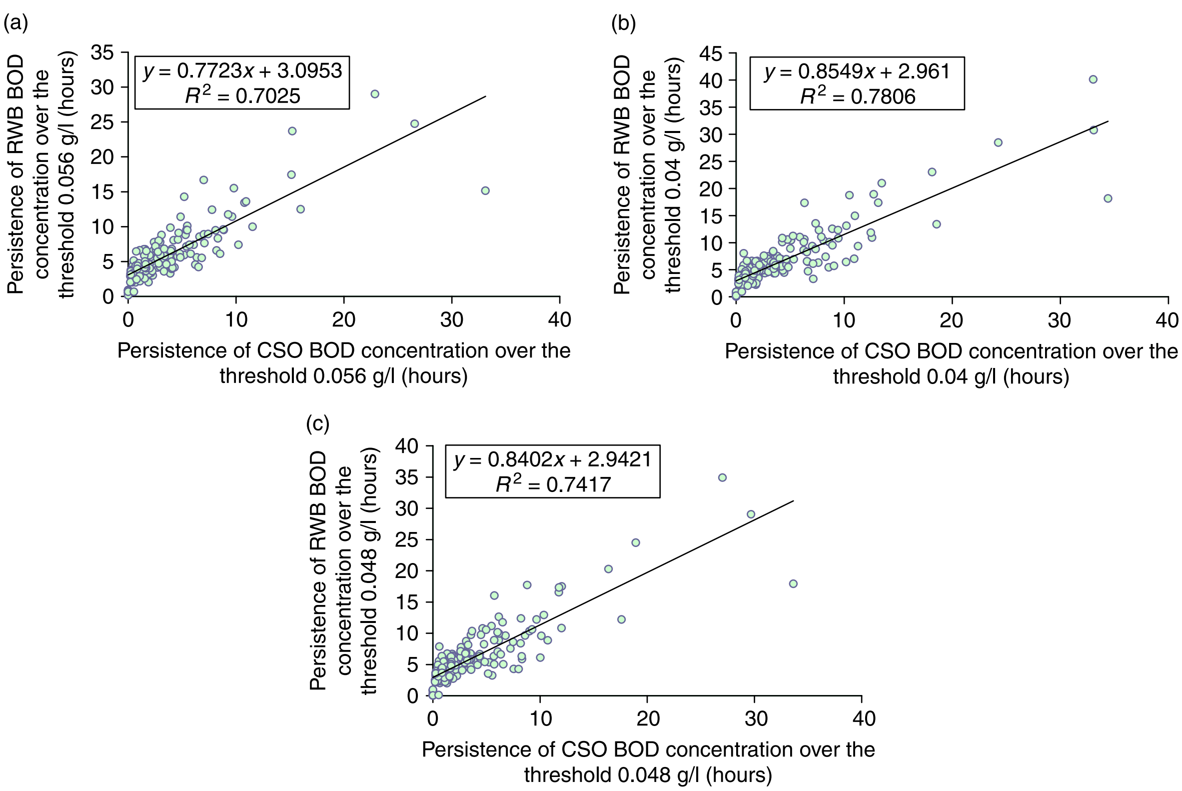

Figure 6 | A comparison of the BOD concentration persistence over the UPM limits in the RWB and at the CSO outfall is shown.

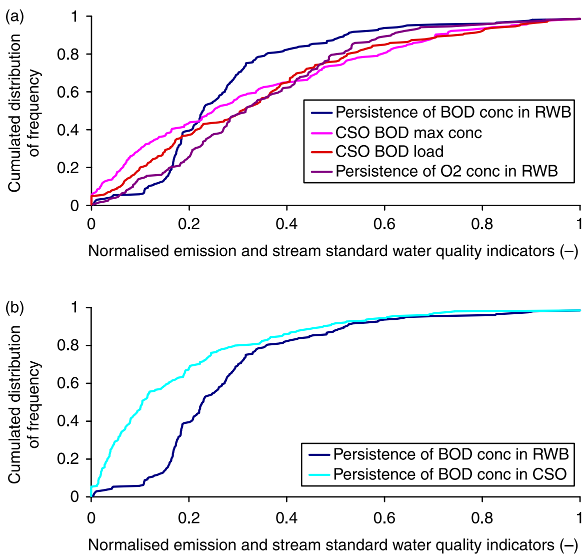

Figure 7 | A comparison of emission standards and stream standards on a frequency basis.

Nevertheless, as the UPM suggests, the use of probabilistic approaches for analysing RWB water quality limits the violations; if a more robust correlation was found using frequency distributions, it would have been valuable for simplifying the required analyses.

To this end, the correlation between the frequency distributions of the FIS applied to the emissions and RWB water quality was explored (third phases). In particular, Figure 7 shows the frequency distributions of some of the considered variables that were normalised based on their maximum value in order to allow for a better comparison. The persistence variables were computed assuming a threshold concentration equal to 0.04 g/l. From Figure 7, the following conclusions can be drawn:

- classical emission-standard variables do not compare well with the UPM limits considering the frequency distributions, suggesting that these variables cannot be compared (Figure 7a); in particular, the emission-standard variables have convex distributions with higher probability densities for the lower values of the variables, while the UPM variables have more uniform distributions.
- the application of the UPM limits to the CSO discharges is an adequate surrogate for the RWB analysis, at least for low frequency events. Indeed, for a return interval greater than 30 days (or, in the present case, for a cumulated frequency equal to 0.8), the CSO BOD persistence cumulated frequency distribution agrees well with the equivalent curve for the RWB BOD (Figure 7b).

A comparison of the two frequency distributions mentioned above provides insight into the dependency of the RWB FIS on the WWTP surcharge. In fact, when the BOD loads coming from CSO are small, the loads coming from the WWTP failure are relevant and the correlation between the CSO behaviour and RWB behaviour is not consistent. For less frequent events, the impact of the CSO covers all other processes and the correlation becomes relevant. This result also confirms the importance of selecting an appropriate modelling approach that is able to investigate such transient phenomena.

In order to detect if there is a correlation for cumulated distribution frequency values lower than 0.8, an iso-frequency analysis was carried out. In Figure 8, two emission-based indicators were related to the persistence of the RWB BOD concentration over the UPM limit.

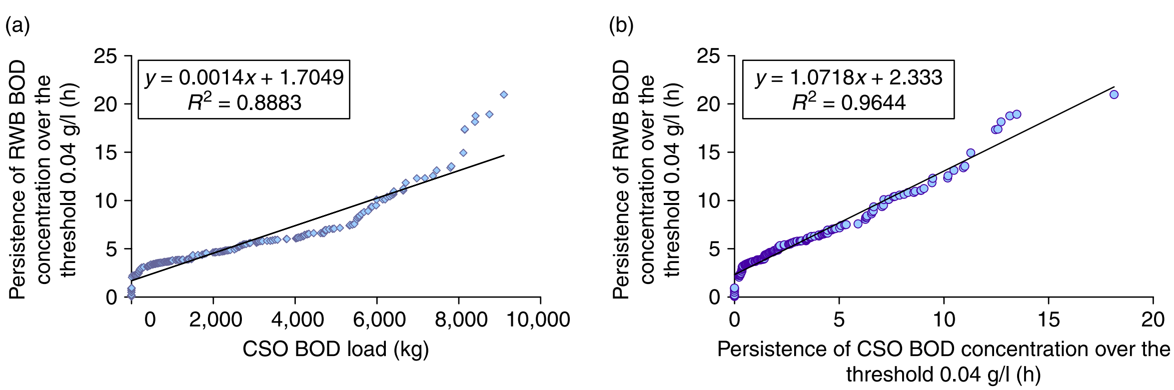

Figure 8 | The correlation between the emission-standards vector and the stream-standards vector oriented according to their frequencies.

Both the emissions and stream variables were sorted in ascending order. A comparison between the two graphs shows differences between the behaviour of the two emission-standards: CSO BOD load has a greater error for the RWB UPM limit violation, thus confirming that a correction factor cannot be found that allows the emission standard to directly predict the FIS violation frequency. On the other hand, the CSO BOD concentration generally underestimates the RWB BOD concentration; however, the relatively linear relationship between the two variables allows this underestimation to be corrected, thereby reducing the systematic error.

The functional dependency shown in Figure 8 can thus be used to simplify the modelling approach and obtain the RWB water quality of the simulated urban drainage system.

CONCLUSIONS

A long-term integrated water quality model was set up by analysing all of the components of the drainage system: the SS, WWTP and RWB. The main goal of this study was to investigate the correlation between the RWB quality and its precursors, i.e., urban polluting discharges. Specifically, this study focused on ephemeral streams where the water quality is highly related to the urban discharges and the analysis was aimed at finding a usable correlation between the impact of the pollution on the RWB and emission-based water quality indicators.

Therefore, a correlation survey was performed for the emission based CSO indicators and the RWB stream indicators as defined by the UPM and often adopted in Europe for compliance with the WFD. This correlation can be useful for combining the advantages of emission-standard methods (grading polluting sources on the basis of the magnitude of their emissions and simplifying analysis approaches) and stream-standard methods (identifying the real impact of polluting load on the RWB).

The main results of the study can be summarised as follows:

- a correlation between the stream-standards (particularly, those provided by the UPM) and classical emission-standard variables is not possible because of nonlinear processes;
- a correlation is possible when the same UPM procedure is used for the CSO emission and the RWB water quality; this allows for some optimism in stating the comparability between emission and stream-standards. However, it has to be stressed that this type of correlation cannot guarantee an exact determination of the RWB quality from the FIS emissions;
- the correlation is better when analysing the polluting process of an event–the frequency field, as stated by the UPM procedure, allows one to use the persistence of the CSO BOD concentration as an adequate surrogate for the persistence of the RWB BOD concentration;
- in the case study examined here, the correlation is good for frequencies higher than 30 days (with a cumulative frequency equal to 0.8) that are more interesting in terms of UPM limitations;
- cumulative frequencies lower than 0.8 can be still correlated by correcting the relationships between the frequency distributions by means of a relationship derived for the analysed case study that filters the systematic error.

The presented results were formulated by using the simulations of a calibrated and validated mathematical model; the obtained conclusions should be progressively verified once new data become available. In such cases, modelling uncertainty should be always considered when simulation results are compared with regulation limits or they are used for planning or design.

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