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New simple methodology to estimate degree of dilution in CSO discharges from sewer systems

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NEW SIMPLE METHODOLOGY TO ESTIMATE DEGREE OF DILUTION IN CSO DISCHARGES FROM SEWER SYSTEMS

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INTRODUCTION

Performance measures relating to combined sewer overflow (CSO) operation are widely known to have limitations. In the UK they have evolved from simplistic settings based on six times dry weather flow, to Formula A (Government, 1970) and eventually to more complex consent conditions of spill volumes, spill frequency and water quality. Performance measures related to the quality of the receiving waters have also been developed in an attempt to better represent the impact of CSO spills. However, difficulties associated with measuring CSO spills and associated river flows (including the forecasting of events, taking a representative number of water quality samples, and the general costs of this type of activity) make it very difficult to accurately quantify CSO performances (Blanksby, 2002).

From a network modelling point of view, consent conditions are still a valid first step for assessing CSO performance where a computational model has been built and adequately calibrated. This initial assessment can help to identify the critical CSOs, allowing the prioritisation of resources in these areas. This is particularly useful outside of the UK, where sometimes there is less of a tradition for computational modelling (in particular calibration and verification against survey data) and there are less economical resources available.

In these circumstances, ideally three performance measures should be determined from the model: spill volumes, spill frequency and degree of dilution of the spill. The use of long time series rainfall (based on historical or synthetic data) is common practice these days for defining spill volumes and spill frequency. However, methods for determining the degree of dilution tend to be based on a large number of assumptions and, therefore, this performance measure is often neglected. It is widely accepted that overflow spill volume and spill frequency, used with care, can be considered as receiving water quality impact indicators (Lau et al., 2002). However, two different CSOs with the same spill frequency and spill volume could have very different pollution loads. An estimation of the degree of dilution helps to quantify this and allows a comparison between the performance of different CSOs for a same catchment area.

A new and simple methodology to determine the degree of dilution is presented in this paper. This methodology is based on using the

Water Quality model available in InfoWorksCS as a 'tracer' for foul flows. This methodology is illustrated with a real-life example: the Fano sewer Master Plan (Italy), where HR Wallingford assessed CSO performance for the local drainage company. The strengths and limitations of this methodology are discussed in the conclusions of this paper.

DEGREE OF DILUTION

The following definitions apply to the remainder of this paper:

Dilution: The fraction of foul flow present in a pipe at a particular point in time:

$$D = \frac{Q}{Q_f} \qquad (1)$$

where D is the dilution in a pipe, Q is the total flow rate of this pipe and Q_f is the foul flow component. A dilution equal to 1 means that the flow is entirely made up of foul flow. A dilution equal to 2 means that 50% of the flow is foul flow and 50% is stormwater flow. During a storm event the degree of dilution in a pipe will vary over time (Figure 1).

CSO average dilution: The fraction of foul flow present in the total spill volume. For every spill event an average dilution value can be calculated. This value, in combination with the minimum dilution, can give an idea of the dilution characteristics of the CSO spill for a particular event.

CSO minimum dilution: This is the most polluted discharge from the CSO during a particular spill event. This is usually when the CSO first starts to spill, when the foul flow in the system has not been heavily diluted by the stormwater flows (Figure 1). However, this is not always the case. For instance, a CSO can sometimes receive heavily polluted reverse flows after it has already started spilling. A significant daily variation in foul coupled with a CSO that can spill during low intensity rainfall can also lead to a delayed minimum dilution.

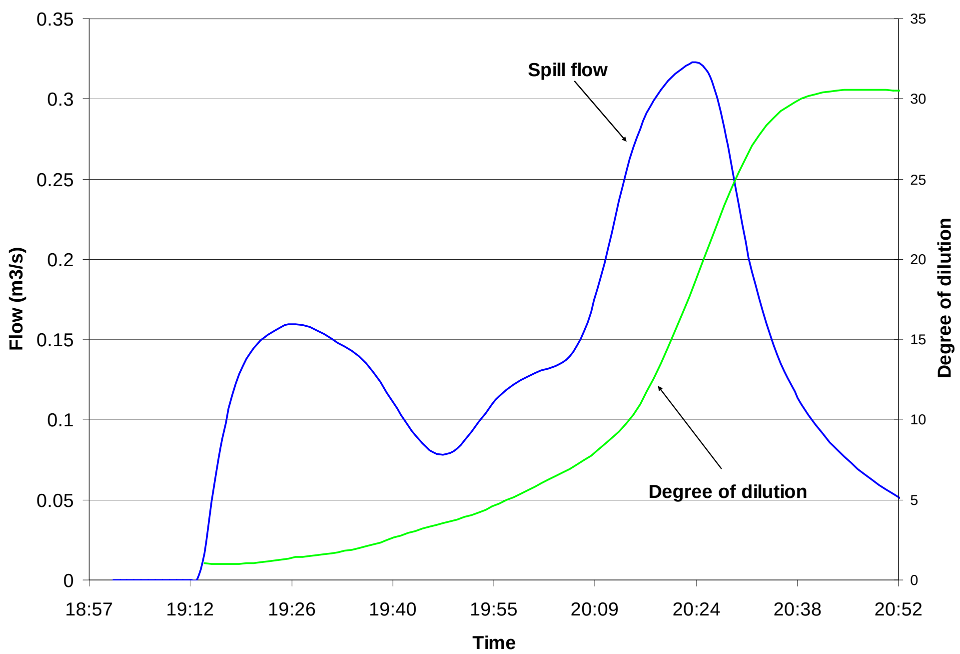

Figure 1 Variation of degree of dilution and spill flow rate in a CSO during a spill event

Traditionally, minimum dilution was calculated as the quotient of the CSO setting (i.e. the pass forward flow of the continuation pipe at the time of first spill) and the dry weather flow component in that pass forward flow:

$$D\min = \frac{Setting}{DWF} \qquad (2)$$

This calculation is based on two assumptions:

Minimum dilution happens at the first spill.
The CSO is not affected by downstream conditions.

However, as discussed above, there are occasions when these assumptions are inappropriate. These assumptions are also implicit in the methods that use six times dry weather flow or Formula A. Therefore, there are many occasions when these methods are redundant.

An additional problem when applying Equation (2) is deciding which dry weather flow to use in the calculation: average dry weather flow, peak dry weather flow or equivalent dry weather flow (i.e. determined on a dry weather day at the corresponding time of day that the spill event starts). The use of different flow rates can give in some cases very different results.

METHODOLOGY DESCRIPTION

The InfoWorks CS Water Quality model allows you to simulate the build-up of sediment in the network and the movement of sediment and pollutants through the drainage system during a rainfall event (Wallingford_Software, 2009). It is not the aim of this paper to explain the details of this water quality model, but as seen in Figure 2 there are different ways in which pollutants can be represented.

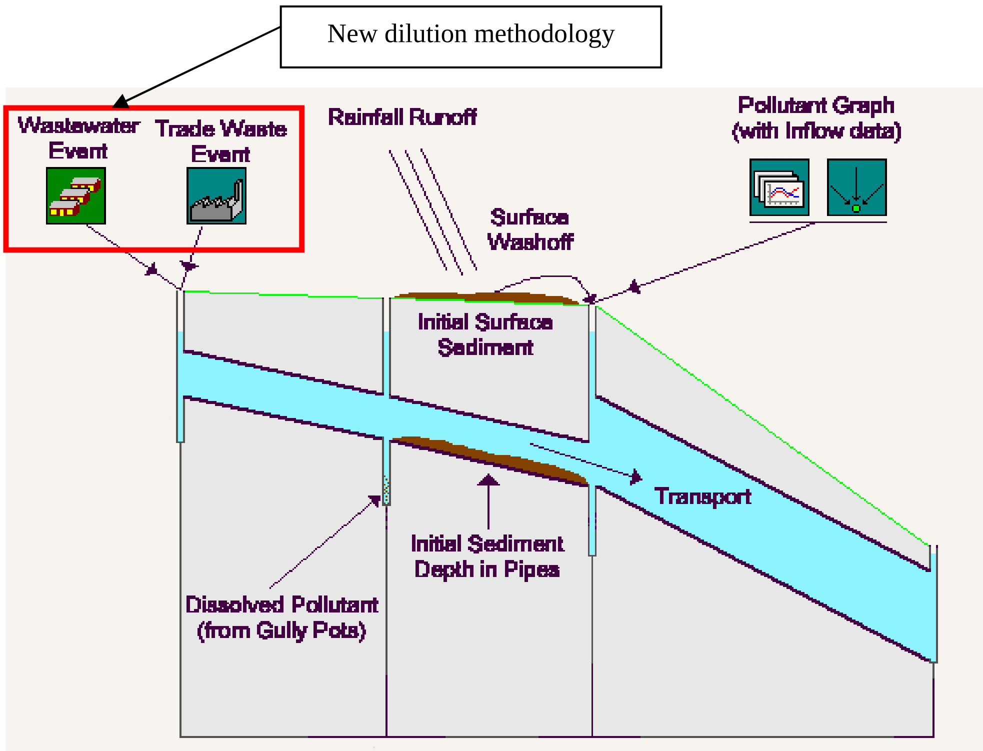

Figure 2 Components of the water quality model in InfoWorksCS

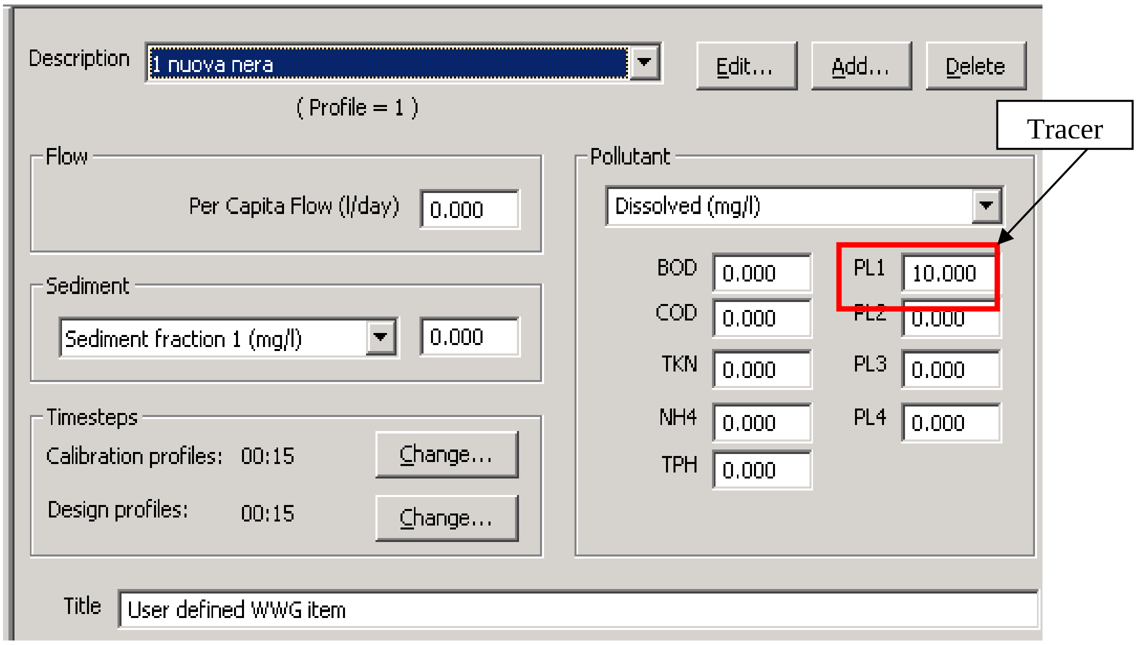

Figure 3 Waste water profile with waste water tracer

The methodology describe in this paper is based on a simplified used of this water quality model, using a dummy dissolved pollutant as a 'tracer' for foul flows. A constant concentration (i.e. 10 mg/l) is associated with every foul inflow through one of the "user defined" pollutants available in the waste water profile (see Figure 3). The InfoWorks CS water quality engine assumes pollutants to be completely mixed and only models advection of pollutant and not dispersion (Butler and Davies, 2000). Consequently, the dummy pollutant will only get diluted when foul flows actually mix with storm flows. Therefore, knowing the concentration of the pollutant in a particular pipe, it is easy to calculate the degree of dilution.

For instance, if the concentration of pollutant in a particular pipe is 2mg/l and a 10mg/l tracer concentration has been used (as in Figure 3), the degree of dilution of the foul flow passing through this pipe is 5 (10/2).

Trade flows can also be included in this methodology in two ways:

- Use the same dummy dissolved pollutant and applying an appropriate concentration to each trade flow (this might be the same as that used for the foul flow or scaled up or down).
- Use a different dummy dissolved pollutant exclusively for trade flows. Two different degrees of dilution are calculated: one for foul flows and the other for trade flows.

The main advantages when calculating the degree of dilution using this methodology are:

1) It can be applied to CSO spills that include reverse flows or are affected by downstream conditions (which depends not only on the CSO dimensions but also on the size and the shape of the event modelled)
2) The variation in the degree of dilution during a spill event can be determined, not only the minimum dilution. Therefore, average dilution can also be determined.

3) It is easy to spot if the minimum dilution is not at the time of first spill and this can be calculated correctly.

When using a long rainfall time series, minimum and average dilution values can be obtained for every spill event at each CSO. This generates a data set for each CSO that can be statistically presented in a number of different ways (e.g. mean, median, range, standard deviation, etc.)

Ideally, this methodology should be used with verified models and should not be considered as a substitute for detailed water quality modelling, but it can be used as a complementary tool as part of an initial assessment of CSO performance.

The degree of dilution, as defined in this paper, only considers foul flows and does not include other sources of pollution such as surface washoff, pollutants from gully pots or initial sediments in pipes. Rainfall runoff is assumed to be "clean" and the flushing effect of storm flows is neglected. Therefore, the degree of dilution should not be used as an absolute water quality parameter, but as an additional way of comparing the performance of different CSOs in a network.

Other assumptions that are inherent in this approach because of the limitations of the InfoWorks CS Water Quality Model include the following:

- Storm water moves at the same velocity than the foul base flow. This is not the case during the first flush wave although this effect is mitigated by the flows coming from lateral branches (Butler and Davies, 2000).
- Pollutants are completely mixed and are conveyed through the pipe at the average flow velocity.

CASE STUDY: THE FANO SEWER MASTER PLAN (ITALY)

HR Wallingford was commissioned by the local water utility company (ASET Spa) to carry out the master sewer plan for the city of Fano, on the Adriatic coast of the Marche Region. Fano is a popular beach resort and is the third most populated city in the province of Pesaro and Urbino with approximately 62,000 inhabitants (www.comune.fano.pu.it). It was founded by the Romans around 207 BC having a strategic position where the Via Flaminia (the road linking Rome and Eastern Italy) arrives at the Adriatic Coast. Interestingly, the historic centre of Fano still uses many sewers built during Roman times. These pipes generally have brick arch cross-sections with heights of up to 2m and widths up to 1.5m.

The main objective of the study was to analyse and propose solutions for the frequent and severe flooding problems caused by the city's combined sewerage network and to assess CSO performance, in particular the CSOs that spill closest to the bathing areas.

The modelled catchment covered the whole of the urban area of the city (approx. 650ha). The terrain included very flat areas (in general very close to sea level) and fairly steep areas close to the historical centre that was built on a high spot. The catchment is limited to the south-east by the River Metauro, in the north-east by the Adriatic Sea, and it is intercepted by the Arzilla Stream, the Albani Canal and the Ancona-Rimini Railway line (Figure 4).

A model of approximately 5300 nodes was built and verified in InfoWorks CS (Figure 5). This included a 2D surface component to gain a better understanding of overland flow paths and ponding areas. The system has 19 pumping stations and 37 CSOs (10 spilling to the sea, 11 spilling to the Arzilla Stream, 15 spilling to the Albani Canal and 1 spilling to the River Metauro). The system drains to Ponte Metauro Wastewater Treatment Works (WwTW), which discharges treated effluent into the River Metauro, close to the estuary.

Figure 4 Areal view of catchment

Figure 5 Areal view of the network projected into Google Earth TM

Six different schemes were developed to address the main flooding problems in the catchment. The impact of these schemes on CSO performance was quantified.

A seven-year rainfall time series was also run through the model to asses CSO performance. Annual spill volume and spill frequency were calculated for the 37 CSOs for existing and future scenarios, with and without implementation of the proposed schemes. Initially, the traditional approach was used to measure the degree of dilution (as in Equation (2)). Using this approach it was found that approximately 30% of the CSOs were giving negative dilution rates (due reverse flows in the continuation pipe), which was clearly nonsensical. Therefore, it was necessary to find another way of estimating the degree of dilution of these CSOs. It was then when the idea of using the water quality model as a tracer of the foul flow was developed.

The long rainfall time series was run again. Minimum dilution and average dilution were calculated for every CSO and for every event (Figure 6 and Figure 7). The median minimum dilution and the median average dilution were also calculated to give a more general overview of CSO performance.

Simulation times with the water quality model compared to those without increased on average by 30%.

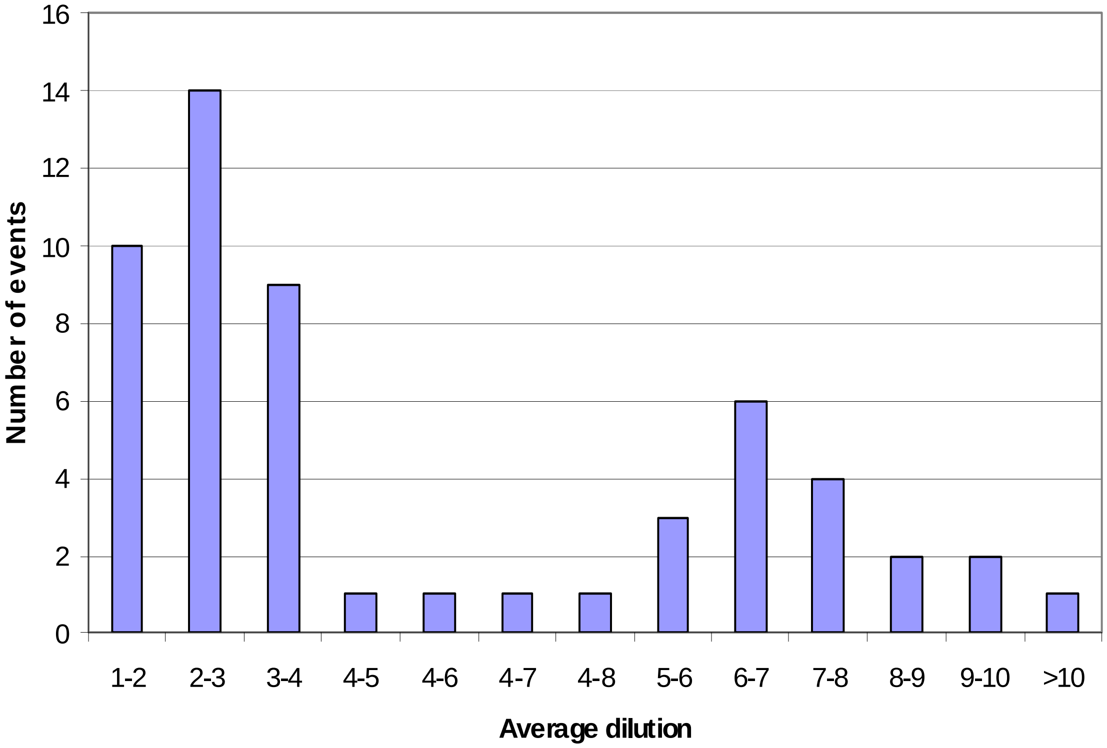

Figure 6 Histograph of average dilution for a CSO in Fano

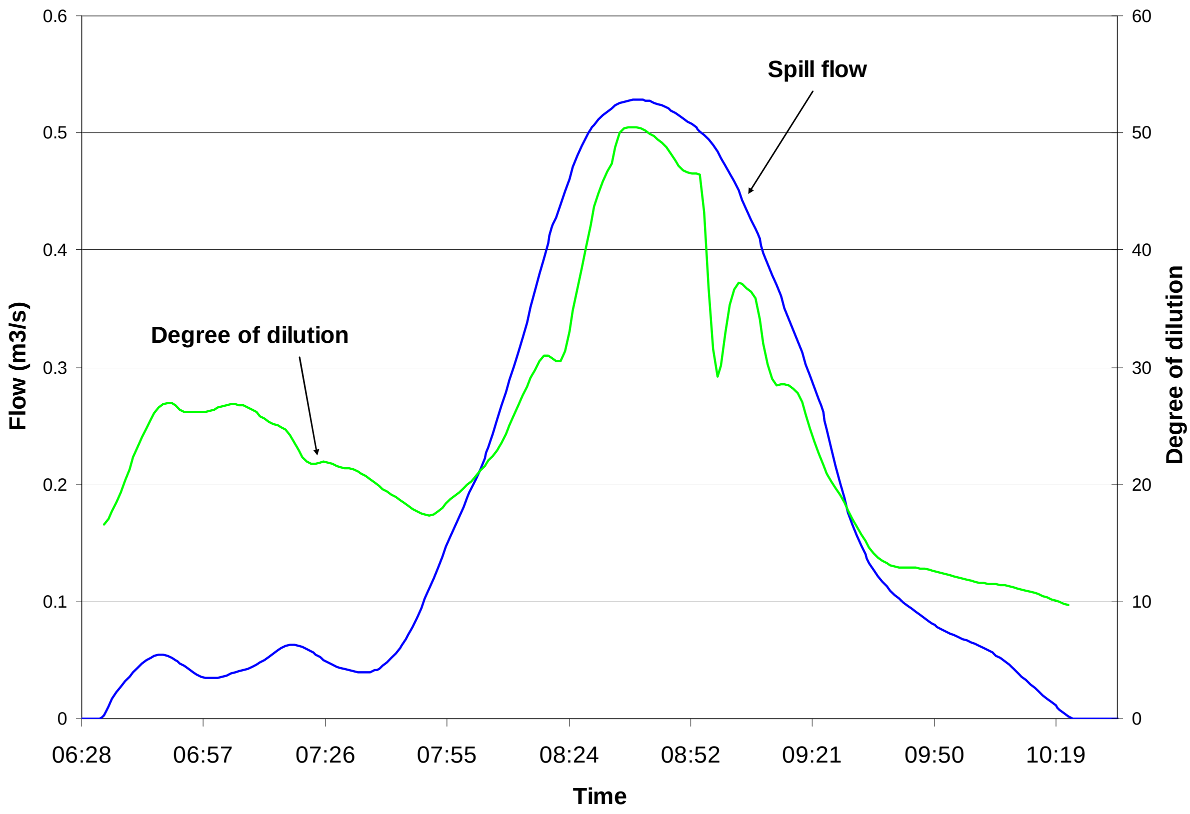

Figure 7 Example of a case where minimum degree of dilution does not happen at first spill

DISCUSSION AND CONCLUSIONS

A simple methodology has been developed to calculate the degree of dilution in CSO spills using the water quality model available in InfoWorksCS as a 'tracer' for foul flows. This methodology provides an additional CSO performance measure with limited time or cost implications. This can be use in conjunction with spill frequency and spill volume to assess CSO performance.

This methodology has the advantage of still being applicable to CSOs that are affected by reverse flows or downstream conditions, unlike traditional methods including Formula A. These methods are still widely used across Europe as CSO design criteria (Zabel et al., 2001). This proposed new methodology is much more effective in assessing CSO performance. In addition, this methodology determines the variation in the degree of dilution during the spill event, as well as the minimum dilution.

The methodology was successfully used for a real-life consultancy project: The Fano sewer Master Plan (Italy) where a combined sewerage system with 37 CSOs was assessed.

This methodology should not be considered as a substitute for a detailed water quality model, but it can be used as a complementary tool as part of an initial assessment of CSO performance. It should be borne in mind that the degree of dilution as determined by this methodology, only considers foul flows and does not include other sources of pollution.

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