Friulian Journal of Science **17**. 2012-13, 19-28

Sustainable stormwater management: an analysis of the industrial area of Buia & Osoppo (Udine)

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Abstract. In environmental engineering, stormwater can be a potential problem not only because of the large quantities of liquid to be controlled, but also because a lot of pollution is conveyed with it; in fact, when water flows over impermeable surfaces, substantial amounts of various contaminants are dragged away to the overflows. The present study aims to model and calculate the *first foul flush* phenomenon by using software EPA SWMM 5.0 in a case study. *First foul flush* makes reference to the higher level of pollutants in stormwater flushing asphalt-concrete or concrete surfaces, mainly in industrial and parking areas, during the early phase of a precipitation event; this polluted surface runoff needs to be collected and treated in a wastewater treatment plant. Before proceeding with the calculations, current methodologies, as well as their theoretical foundations, have been examined. In short, the study has aimed to provide a comprehensive approach to first flush management, using theoretical bases, practical experiences and numerical models.

The case study concerns the hydro-environmental status of CIPAF (Consorzio per lo Sviluppo Industriale ed Economico della Zona Pedemontana Alto Friuli) industrial park. In this area stormwater flushing of impervious surfaces is a critical issue, since powders, scales and other residues resulting from the ordinary activities carried out by the factories located nearby produce, during a rain event, a huge amount of materials to be treated in the wastewater treatment plant. The present study tries to describe the phenomenon of polluted surface runoff, offering a contribution to understanding how and when contaminants reach the treatment plant with respect to waterflow rate peaks. A validated rainfall model has been used, with some considerations and analysis referring to the specific case study.

Key-words. Stormwater, wastewater treatment, dynamic simulations.

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1. Introduction. In recent years, greater climate variability and an increasing awareness of environmental issues on the part of policy-makers have highlighted the importance of a sustainable use of water supplies. In Italy examples of good practice are relatively scarce, but something is moving in the right direction, with a growing interest for the harvesting of rooftop rainwater and the adoption of water-saving measures in many homes.

The general problem of a sustainable use of water resources is explained by the two concepts of hydraulic and hydrological invariance. Hydraulic invariance indicates that we cannot continue to reduce permeable surfaces by covering them with asphalt or concrete, without worrying about possible flooding generated by rainstorms. In fact, professionals designing a new parking lot or a housing project are now required to control stormwater flow peaks. Hydrological invariance, on the other hand, deals with maintaining floodwater volumes before and after waterproofing the soil. Figure 1 gives a graphic illustration of the two concepts mentioned above.

A new approach to project design, therefore, must accommodate the natural tendency of the ground to drain floodwaters. Equally, each activity having an effect con the environment should be carefully planned in order not to create situations that will compromise the control over water quantity and quality. In this respect, the adoption of more efficient sewage systems and a wide-area approach to flood reduction and stormwater treatment are going to be more effective than conventional methods using centralised treatment plants and stormwater tanks: actions on a vast area mean an involvement of different players, working in synergy

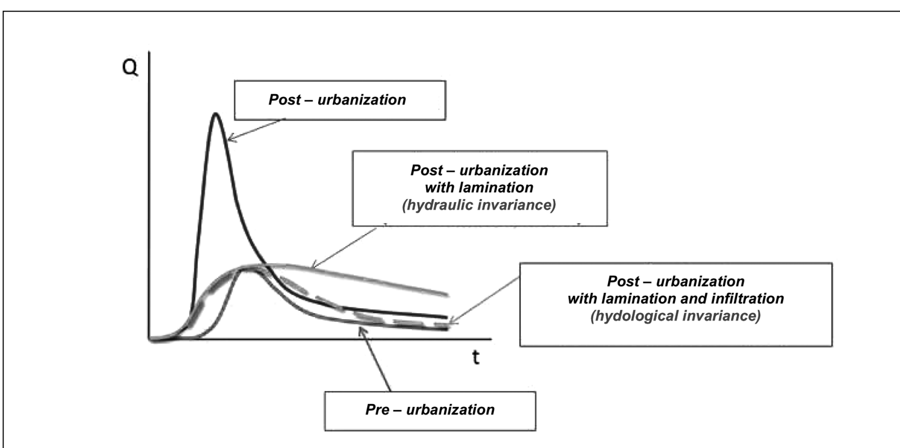

Figure 1. Hydraulic and hydrological invariance.

in order to solve the problem of stormwater management. Similarly, we need a comprehensive approach to the management of the wide range of pollutants dissolved in stormwater: pollutants are everywhere, so water picks them up wherever it flows and this creates a variety of problems.

The following study aims to provide a mathematical and physical basis to improve the understanding of these phenomena and to find a way to deal with them effectively.

2. Stormwater: qualitative and quantitative aspects. When it rains, water flushes impervious surfaces at different speed, finally being collected in the drainage system: this process is called runoff. As the level of permeability decreases, the quantity of runoff water entering the drains increases.

But the problem is not only related to quantity: when crossing the atmosphere, rainwater collects suspended particles of pollutants pro-

Table 1. Main pollutants flushed from surfaces by rainwater in urban areas.

Categories	*Parameters*	*Source*	*Effects*
Sediments	TSS, turbidity, dissolved solids	Construction sites, urban/agricultural runoff, landfills, septic fields	Turbidity, habitat alteration, contaminant transport, bank erosion
Nutrients	Nitrate, nitrite, ammonia, organic nitrogen, phosphate, total phosphorus	Urban/agricultural runoff, landfills, septic fields, atmospheric deposition, erosion	Algal blooms, ammonia toxicity, nitrate toxicity
Pathogens	Total coliforms, faecal coliforms, faecal streptococci, viruses, E. Coli	Urban/agricultural runoff, septic systems, illicit sanitary connections, boat discharges	Ear/intestinal infections, imperfect shellfish closures
Organic enrichment	BOD, COD, TOC, dissolved oxygen	Urban/agricultural runoff, landfills, septic systems	Dissolved oxygen depletion, odours, fish kills
Toxic pollutants	Toxic trace metals, toxic organics	Urban/agricultural runoff, septic systems, pesticides/herbicides, underground storage tanks, landfills, industrial discharges	Bioaccumulation in food-chain organisms and potential toxicity to humans and other organisms
Salt	Sodium chloride	Urban runoff, snowmelt	Vehicular corrosion, contamination of drinking water

duced by industrial and natural processes. When it reaches the ground, it collects the particles of pollutants deposited on impervious ground cover or on roofs and drags them to the drains, producing a huge amount of waste substances (organic or non-organic) that need to be treated. Table 1 describes the most important categories of pollutants in urban areas, as defined by EPA (1993). The source of these substances and the effect of their presence are also reported in Table 1.

Naturally when examining a particular area, such as CIPAF, we need to assess exactly which specific contaminants are present and could be flushed to the treatment plant. Table 1, however, is a good starting point; also we can presume that, in urban areas such as CIPAF, the most common pollutants will be sediments, salts and hydrocarbons coming from the gas exhaust of internal combustion engines (vehicles).

In order to control pollution and the volume of runoff water flowing into the drains, we should also take into account the flow rates deriving from a rainfall – so the problem needs to be examined from an hydraulic point of view. Pollution and flow rates should be evaluated at the same time, so we talk about quali-quantitative control of stormwaters. Several approaches can be used to manage this complicated process: the conventional approach is a centralized method consisting in overflow outlets, detention basins (but only in very rare cases) and stormwater tanks.

As we said before, wherever possible, a modern wide-area approach has

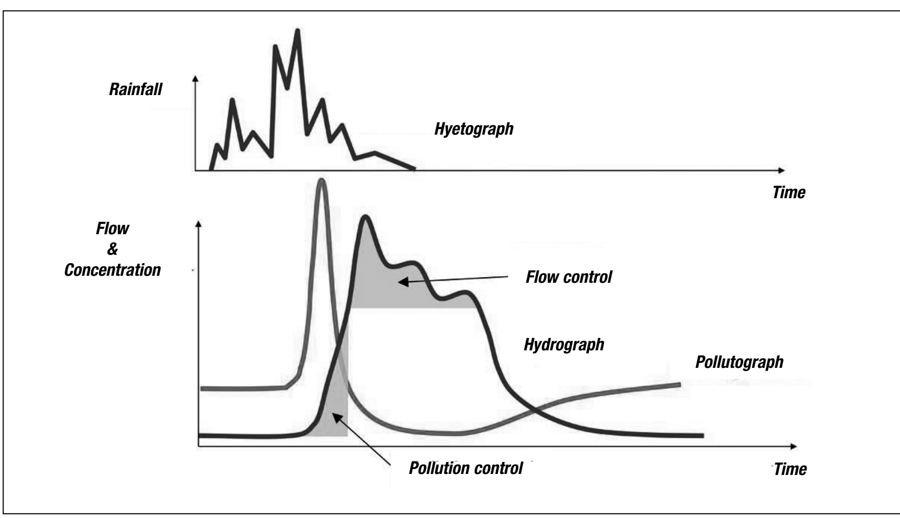

Figure 2. Parts of flood hydrograph to be monitored to solve the quali-quantitative problem of first-flush water.

to be preferred, supplying pre-treated waters to the treatment plant and then discharging them into a river or into the sewerage system; Figure 2 shows the present quali-quantitative problem and the ways to control flow rates and pollution.

3. First flush. This study has looked into the subject of stormwater runoff from impervious surfaces and into ways of tackling the problem by using simulation models. Conventional approaches used to apply very rough criteria to calculate the size of stormwater tanks – mainly coefficients based on the impervious areas. For example, one of the most widely-used criteria was to spill in a stormwater tank the first 5 mm of runoff that, for the purposes of the model, were thought to have fallen in the first 15 minutes of a storm. But the first-flush phenomenon is really much more complex than this, so this calculation alone will not suffice. Instead, we should accurately study the territory where these simplifications are applied, otherwise we risk to overestimate or underestimate the extent of the “first foul flush”, and therefore the tank size.

Unfortunately, first-flush regulations tend to be fairly obsolete in Italy. In recent years some improvements have been made, but only in certain regions such as Lombardy, Veneto and Emilia Romagna, which have adopted more advanced and stricter regulations; in any case there is still a lot to do. This article, however, concentrates on the technical aspects of this question, in particular on modelling the flushing of settled substances on im-

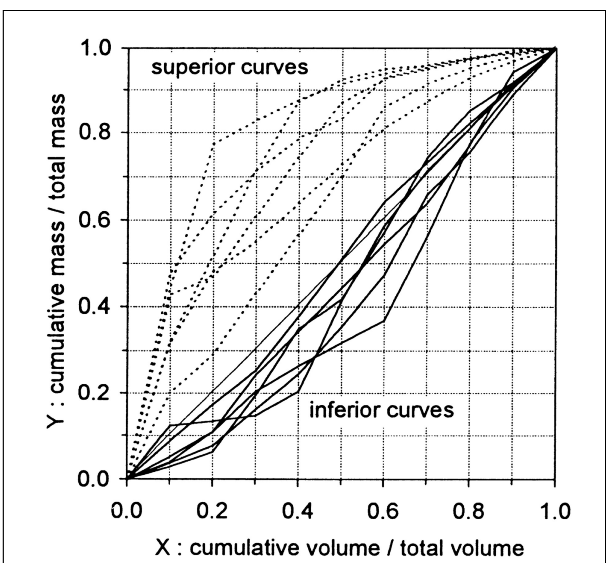

Figure 3. Examples of M(V) curves for the analysis of the first-flush phenomenon.

permeable surfaces and understanding how they reach the treatment plant.

The first-flush phenomenon is influenced by the activities taking place in a certain area. Once the substances produced by a specific activity are known, we can analyse them by using mass-volume curves M(V).

These curves let us calculate the total mass of the substances dissolved in stormwater; obviously this has to be supported by measurements regularly repeated over time. A better procedure would be to analyse the concentrations for at least one year in order to understand how an urban watershed behaves in terms of contaminants dissolved in the drains. This will allow us to evaluate how to optimise wastewater treatment and first-flush collection.

4. Case study: the industrial area of Buja & Osoppo. Founded in 1966, CIPAF Industrial Consortium has expanded over the years and now includes 44 members. CIPAF is located at the foot of the Friulian Prealps, to the north of Udine, within the municipalities of Buja and Osoppo; the River Tagliamento flows some distance to the west of the area. Figure 4 shows the stormwater drainage system connected with a waste treatment plant located in Via Saletti. The only direct overflow outlet is located on the eastern drain.

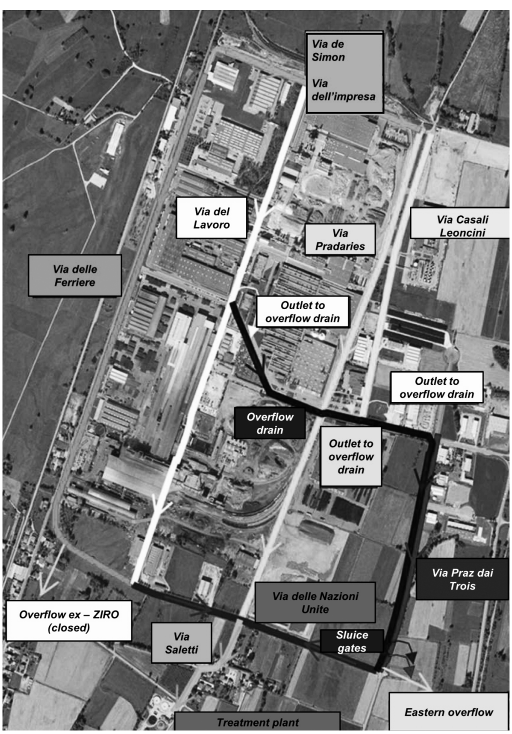

Figure 4. Stormwater drainage system of CIPAF (2011).

The major issues of the drainage system are due to material flushed away by runoff water. This material accumulates when it arrives at the treatment plant, and this affects its optimal working conditions. We will now try to explain how a computational model can help to understand the first-flush phenomenon.

5. The EPA SWMM software and the CIPAF modelling. In order to model stormwater runoff and first flush, we have made reference to the drainage network model developed by the commercial software EPA SWMM and validated by Cabai (2011). This model converts water quantity into flow rate in the drainage network. It comprises two modules: an hydrological model converting rain into input for the drains, and an hydraulic one solving the equations representing the transport of water to the outlet of the drainage network.

At this stage the target is to understand how the substances are transported in the drains and to model the behaviour of pollutants. This requires to define land use, that is the type of activity taking place in a specific area. Table 2 summarises land use in the case of CIPAF; for each type of activity it indicates the substances that we expect to be produced in that area (working as parameters of the EPA SWMM model), and which will later be flushed by stormwater.

Once we have established the composition of pollutants and their area of production, we need to understand how they are produced and how they are flushed. This requires to define the buildup and washoff functions in the software. These functions are exponential because they seem to be closer to the real physical phenomenon.

When the hydraulic model is

Table 2. List of pollutants defined in the EPA SWMM model of CIPAF.

Area	*Pollutant*
Roads	TSS_GENERIC_ROAD
Mill	TSS_INORG_LAMELLA, TSS_INORG_AGHI, TSS_INORG_FINE
Foundry	TSS_INORG_AGHI, TSS_INORG_FINE
Furniture factory	TSS_ORGANIC_FIBRE, TSS_ORGANIC_FINE
Road granules	TSS_INORG_FINE
Mechanical industries	TSS_INORG_FINE
Parking lot	TSS_GENERIC_SQUARE
Roofs	TSS_GENERIC_ROAD
Timber storage	TSS_ORG_FIBRE

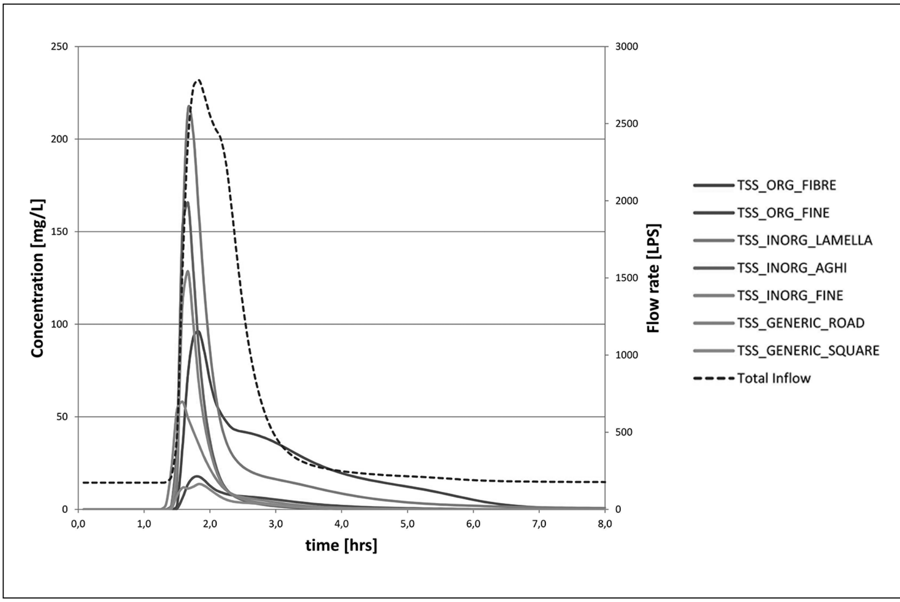

Figure 5. Simulation of a 20 mm precipitation event falling in half an hour (results refer to the outlet of the treatment plant).

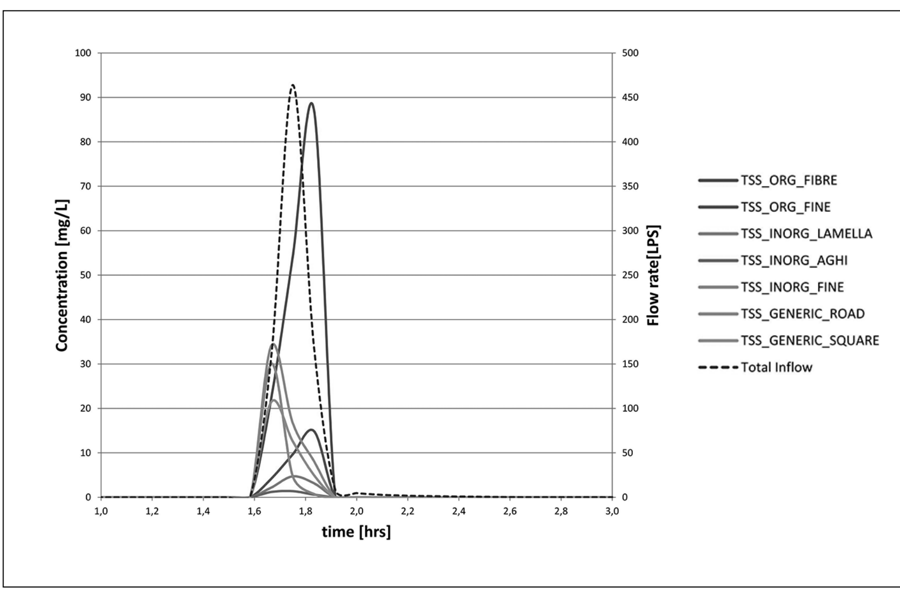

Figure 6. Last-flush phenomenon at western overflow outlet for 20 mm of stormwater in 30 minutes.

ready and the functions are fully defined (settling and flushing of pollutants), the simulation is ready to run. Several simulations have been launched which have allowed us to examine long-lasting precipitation events, but the most critical condition is when sudden storms occur – this means a vast quantity of water falling in a few minutes. This also means that large and violently impacting water drops are more effective in picking up settled particles on impermeable areas.

Simulations have shown that the peaks in pollutant concentration anticipate the peaks in waterflow rate, and this has suggested possible ways to manage stormwater runoff, which, as we said before, poses serious problems to treatment plants. Figure 5 shows the time delay of the water peak with respect to the pollutants peak.

The time elapsing between the substances arrival at the plant and the waterflow rate peak is the first flush. If there were remote control systems connected with a system of sluice gates, it would be possible to fill a tank with these waters and treat them later.

The “last flush” is another phenomenon which can be observed by simulation: depending on how the hydraulic network is set, the pollutants peak could be postponed instead of anticipating the water peak.

Figure 6 shows this phenomenon at the eastern overflow outlet, mostly caused by wooden debris in the stormwater runoff flowing from the northern part of the CIPAF site.

6. Conclusions. Even if based on limited information on the area under examination, this work has helped us establish how pollutants are transported in a drainage system. The model should be validated with measuring and sampling activities, so that the problem of pollutants quantity could be studied not only from a technical point of view but also from an economical one. Future developments of the model could include a deterministic design of the drainage and treatment systems, supported by a physical model focussed on the target area. All these considerations point to a change in the technical approach: not only standard practice and an analysis based on average data, but a study supported by numerical models and simulations, providing accurate times and correct modalities to the designing activities.

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