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Do stormwater source control policies deliver the right hydrologic outcomes?

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SUMMARY

The number of stormwater source control (SC) regulations adopted by local authorities is rapidly growing in many countries. We can expect that, in the near future, the hydrologic behavior of many urban and periurban catchments will reflect this diffusion. This paper discusses SC regulations through two complementary approaches: starting on three French case-studies, it analyzes how regulations are developed today and identifies a set of shortcuts in policy-making practices. Then, the hydrologic model of a periurban catchment in the Paris region is used to test the impacts that these regulations can produce if widely applied. The main finding is that inertia in policy-making, driving a singular focus on flow-rate based regulations, can produce negative impacts in the long-term. Further efforts on volume-based regulations are advocated, both in terms of research and policy-making.

1. Introduction

In the last five decades, stormwater Source Control (SC) has gained relevance over traditional sewer approaches, mainly for its potential to cope with fast urbanization and non-point source pollution (Bergue and Ruperd, 1994; Delleur, 2003; Urbonas and Jones, 2001). The principle of SC is to develop, simultaneously to urban growth, facilities to manage stormwater at a small-scale (about 10^2–10^3 m^2) to solve or prevent catchment-scale 10^6–10^7 m^2 stormwater problems. These parcel-scale facilities are usually called Best Management Practices (BMPs) in the USA, Sustainable Urban Drainage Systems (SUDSs) in the UK, *techniques alternatives* in France. Terms like Low Impacts Development (LID) in the USA or Water Sensitive Urban Design (WSUD) in Australia are used today to identify the application of this principle to the whole design of new urban developments, which is typical of an intermediate scale 10^4–10^5 m^2 (Morison and Brown, 2011; Revitt et al., 2008; Roy et al., 2008; Williams and Wise, 2006). In this paper, we will use “BMP” to address individual stormwater facilities, and “SC” when speaking of the catchment scale strategy.

In a first development phase, SC was realized, in most cases, by large reservoirs built to prevent sewer overflows. Then, the principle of diffused small facilities started to be applied, and a pioneering phase of SC policies began (Chouli, 2006). The first regulations enforceable for all new developments date back to the 1980s: the city of Bordeaux, in France (Bourgogne, 2010) started implementing SC policies in 1982, while the State of Maryland, in the USA, in 1984 (Comstock and Wallis, 2003).

Even if no official inventories of local SC policies are available, in several countries (e.g. France, USA, UK, Brazil) their diffusion strongly accelerated in the last ten years (Ellis et al., 2010). In the USA, EPA regulation urges local authorities to adopt policies (EPA, 2010), and a similar effect is expected, in France, for the SDAGE Seine–Normandie (a large-scale catchment management plan, Section 3.4 of this paper). This change of pace is due to a convergence of technical and political rationalities: SC offers an efficient opportunity for urban stormwater drainage and, in the last years, it acquired an halo of sustainable development that increased SC policies appeal for many local authorities (Novotnỳ and Brown, 2007).

Because of the accelerated diffusion of regulations demanding widespread construction of BMPs, we can expect in the near future that the hydrologic behavior of many urban and periurban catchments will be influenced, if not determined, by SC. In most cases, this effect will be driven by the policies that are discussed and implemented today. In France, the Seine-Saint-Denis county (Section 3.2), up to 2009, has prescribed 470,000 m^3 of BMPs on a territory of 236 km^2. Considering an approximate impervious cover of 20%, this represents about 10 mm of storage on the whole impervious area of the county: a value comparable, for example, to weekly mean evaporation.

In view of this relevance, since the 1960s researchers investigate BMPs performances and efficiency. This effort had practical effects, diffusing good design and construction practices. Several BMPs’ selection and design manuals have been published (e.g. Azzout et al., 1994; Bergue and Ruperd, 1994; Clar et al., 2004; Debo and Reese, 2002; Woods-Ballard et al., 2007), that contributed to the actual diffusion of BMPs. However, studies on the global effect of BMPs on a catchment hydrology are still scarce, and so are directions on how to define a suitable policy (Roesner et al., 2001; Roy

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et al., 2008). The transition from a pioneering phase to a rapid and wide diffusion of SC policies makes these questions a priority. If, in the past, efficient design of individual BMPs was the main concern, today it is important to investigate what an effective SC policy at the catchment's scale is.

The hydrological analysis of global effects of SC faces two main difficulties. The first one is that policies effects emerge slowly, at the rhythm of urban growth and renovation. Hence, catchment-wide measurements are still scarce and incomplete (see, for an example, Meierdiercks et al., 2010). Even when data are available, it is difficult to distinguish gradual SC effects from catchment uncontrolled evolutions (Petrucci et al., 2012) or other stormwater management actions, like sewer system developments. The second difficulty concerns spatial scales: passing from parcel-scale BMPs to catchment-scale effects demands a good knowledge of scale-transition processes in urban and peri-urban settings (Cantone and Schmidt, 2009; Chocat and Cabane, 1999). A similar issue has been pointed out for rural small scale surface runoff control measures (O'Connell et al., 2007).

In the absence of comprehensive measurements on catchment-scale effects of SC, researches about this topic have been mainly based on hydrological modeling. Because the purpose of this modeling effort was to extrapolate small-scale known processes (i.e. the behavior of individual BMPs) to predict large-scale unknown effects, most researchers adopted a bottom-up scaling approach (Blöschl and Sivapalan, 1995). In practice, researches on this topic relies mostly on physically-based distributed models (e.g. SWMM, HEC-HMS, MOUSE), allowing for a detailed description of both the BMPs and the large-scale processes. These researches, exploring both water quality (e.g. Freni et al., 2010; Wu et al., 2006) and water quantity effects (e.g. Carter and Jackson, 2007; Emerson et al., 2005; Faulkner, 1999; Goff and Gentry, 2006,: McCuen, 1979; Mouy et al., 2007; Urbonas and Glidden, 1983; Zimmer et al., 2007), allowed to identify some important discrepancy between hydrological studies and actual SC policies (e.g. Booth and Jackson, 1997; Goff and Gentry, 2006; McCuen, 1979).

This paper focuses on these discrepancies: the question is how the policy-making process comprehend – or not – hydrological considerations. In order to answer, this paper integrates two complementary approaches to study SC regulations: at first, it presents a regulations' analysis that aims to make explicit the logics behind SC policy-making; then, it discusses these logics through an hydrological analysis of the catchment-scale effects of SC regulations. Section 2 presents a review of researches on water-quantity catchment-scale effects of SC, focusing on the discrepancies between SC policies and hydrological outcomes. The regulations' analysis is presented in Section 3: three case-studies of SC policy-making are discussed to find how, and on which logics, regulations are developed today. Section 4, through the physically-based distributed model of a peri-urban catchment, assesses consequences, at the catchment-scale, of widely applied regulations. Sections 3 and 4 are based on French cases, but both the methodology and several results could be extended to other countries where SC is developing.

2. Background and research approach

Despite the difficulties highlighted in the introduction, hydrological analysis of global effects of SC provided some general guidance on how to design policies. For example, as BMPs must be adapted to their specific site, SC policies should be conceived according to the specific catchment's characteristics (Ellis et al., 2007; EPA, 2010). Another example is that many researchers, starting with the early analysis of McCuen, 1979, agree on the fact that hydrographs timing must be taken into account when planning storage facilities: a local reduction of hydrographs' peak flow can produce a catchment-scale increase due to peaks' superposition (Fig. 1).

It is surprising that, even if these general ideas gather relevant consensus among scientists, many implemented policies are in contrast with them. Many French policies impose a unique value—often very low—of admitted flow-rate from parcels (i.e. in the form of a $x\,\mathrm{l\,s^{-1}\,ha^{-1}}$ constraint) over entire regions, without considering catchments' specificities or hydrographs' superposition. Some UK regulation shows the same shortcomings (Faulkner, 1999). In the USA, regulations often demand to preserve pre-development peak flow-rates downstream of parcels (Balascio and Lucas, 2009; Fennessey et al., 2001), ignoring peaks' superposition effects (Emerson et al., 2005).

A complementary remark about current policies is that, even if they often involve different instruments to develop SC (e.g. recommendations to infiltrate or reuse stormwater, financial or technical support), most of them fix a regulation on maximum flow-rate downstream of parcels as the only quantified constraint. Today, many scientific works converge in criticizing this kind of flow-rate regulations.

The first critic is that SC policies explicitly or implicitly aim, in general, to preserve pre-development water balance: it has been shown that flow-rate constraints are, in most cases, unable to achieve this goal. In particular, these constraints do not cope with reduced infiltration volumes due to imperviousness, and distort downstream low-flow regimes (Booth and Jackson, 1997; Fennessey et al., 2001). Meierdiercks et al., 2010 analyzed ten years of runoff data to compare three catchments: one undeveloped and two developed, respectively, before and after the adoption of a SC regulation (flow-rate based). In terms of hydrologic behavior, the catchment developed with SC is closer to the one without SC than to the one undeveloped.

The second critic is about peak flow-rate: as stated above, provisions demanding to preserve pre-development peak flow-rate locally, can actually worsen the situation at the catchment-scale (Emerson et al., 2005; Goff and Gentry, 2006; McCuen, 1979), depending on catchment's timing characteristics. Regulations demanding a specific value of flow-rate can have adverse effects on peak flow-rate until the catchment is not completely urbanized, because superpositions between regulated and non-regulated flows can occur. This last type of regulation can also affect intermediary flows, responsible of combined sewer overflows (CSOs). A study of the city of Paris (Mouy et al., 2007) showed that limiting

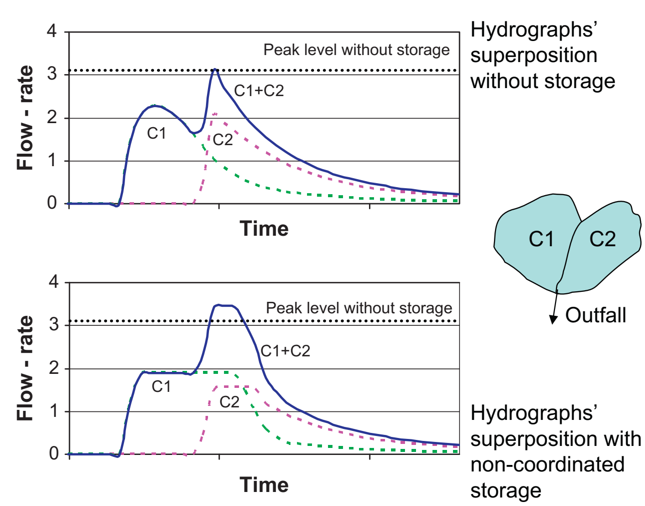

Fig. 1. Peaks' superposition due to storage facilities (adapted from Azzout et al., 1994).