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The potential of green infrastructure application in urban runoff control for land use planning: A preliminary evaluation from a southern Italy case study

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ABSTRACT

Among the approaches for run-off regulation, green infrastructure is identified as non-traditional measure to compensate the effects of soil sealing generated from urban development. It is recognized as a way to increase the provision of urban ecosystem services and is increasingly being used in research and practice on storm-water management through Sustainable Urban Drainage Systems (SUDS). The adoption of SUDS in urban planning might protect hydrological and ecological dimensions of landscapes while providing resilient options to face flood risk management.

This paper shows the assessment of SUDS potential to increase the regulating service capacity in a dense urban catchment in southern Italy. A comparison between scenarios of pre-implementation and post-implementation of SUDS is performed through catchment simulations with a hydraulic model. Results showed different effectiveness of SUDS options, in terms of variations of the indicator chosen as proxy of the regulating service capacity. Results showed a better performance obtained by green roofs than permeable pavements, highlighting a limited capacity of run-off regulation achieved with SUDS deployment in public areas only. This suggests that innovative policies to encourage private land owners to adopt measures of SUDS could be fundamental for the retrofitting of urban settlements.

1. Introduction

Worldwide trends in the increase of impervious surfaces and climate change are leading to the rise of urban flooding (Fratini et al., 2012). Urbanization and precipitation extremes are challenging the city drainage infrastructure (Ferguson et al., 2013; Zhou, 2014) causing great impacts on urban areas, communities, environment and economies (Hammond et al., 2015). The complexity of the urban context requires to manage flooding through policies and practises that should hail from interdisciplinary research and integrated planning (Lawson et al., 2014). Among these, green infrastructure planning is widely accepted in policies for storm water management as an emerging strategy for resilient spatial planning (O'Neill and Scott, 2011; Scott et al., 2013) and to reach environmental and sustainability goals (Fletcher et al., 2014).

1.1. Regulating services and urban run-off regulation

The awareness that not all floods can be prevented is the base of the most recent shift in flood management, which aim at reducing the impacts on urban systems (Schelfaut et al., 2011). Today, several studies are looking at the concept of urban resilience as a new paradigm, which leads to a better integration of issues of water and flooding with city planning and disaster management (Serre, 2011). Under the assumption of cities as social-ecological systems (Carpenter et al., 2001; Folke et al., 2011), it is also frequently pointed out how ecosystems support resilience through the supply of a range of provisioning, regulating and cultural services (Carabine et al., 2015).

In the following, water-flow regulation is considered as a crucial service in urban contexts. The growing emphasis on its relevance for flood prevention and management is conspicuous in the literature on ecosystem services and demonstrated in many studies (Barbedo et al., 2014). For example, Gómez-Baggethun et al. (2013) underline the role of multiple values of urban ecosystem services in improving resilience and quality of life in cities, including the runoff regulation service, that is usually assessed by proxies and indicators such as soil infiltration capacity and percentage of sealed surface. The same authors also refer to biophysical indicators of ecosystem services for economic valuations.

Abbreviations: CN, Curve Number; US EPA, United States Environmental Protection Agency; SUDS, Sustainable Urban Drainage Systems; SWMM, Storm-Water Management Model

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Economic value of water-flow regulation and run-off mitigation comes from avoided costs for increased property damages (buildings, infrastructures, commercial forests and agricultural lands) or for increased dependence on water purification technologies. Moreover, when the loss of regulation of water-flow services is tackled by the substitution of built infrastructure for ecological infrastructure, further extensive costs for society may arise (Gómez-Baggethun et al., 2013). Urban flooding often results in adverse human health effects. It may directly cause deaths by drowning or from diseases caused by contaminated food or water and injury, while many victims of floods may also suffer from psychological and emotional problems (Ohl and Tapsell, 2016). Consequently, land use planning and management strategies are increasingly considering the ecosystem's capacity to regulate water-flow as the most promising way to address the city's capability of dealing with flooding occurrence.

However, in order to apply ecosystem services in practice and decision making, quantifying, modelling and mapping ecosystem services become a very fundamental step (Nedkov et al., 2015). For the evaluation of regulating services, studies and researches differ broadly with regard to applied methods, the selection of assessment criteria, and the spatial scale they refer to. Thus, there is no univocal approach for assessing regulating services and large part of literature demonstrates that methods are still in the development and testing phase (Nedkov and Burkhard, 2012).

Appropriate indicators are needed to quantify the processes by which water flows are regulated in the urban catchment. This requires catchment-scale hydrologic and hydraulic models, as essential tools for calculating indicators that quantify different water-related ecosystem services (Nedkov et al., 2015). The response of catchments to precipitation is affected by different ecosystems and land use elements included in a green infrastructure. The simulation of this response becomes fundamental in order to identify the most effective adaptation strategies.

The crucial issue when dealing with urban flooding is to evaluate how much water can be managed within the system area, considering the amount of water that can infiltrate, be stored in the ground or can be conveyed through drainage systems. Particularly, it has often been stated that the quantity and quality of urban water in cities are mostly influenced by urbanization (Zhou, 2014): soil sealing alters natural drainage by replacing draining soil with impermeable surfaces, leads to changes in the environmental state of the catchments and can affect the ecosystems and water-related services they provide (EC, 2012). These changes exert major pressures on water resources, reduce the amount of rainfall that can be absorbed by the soil, seriously increase the total volume and flow of run-off and might make areas more susceptible to local flooding (Woods-Ballard et al., 2007; Kazmierczac and Cavan, 2011). Thus, existing drainage systems, that have been designed based on a certain return period, may result inadequate to drain the increasing amount of water run-off (Becciu and Paoletti, 2010).

Urban hydrological catchments represent the appropriate scale for water flow analysis (Nedkov et al., 2015) and thus, they are also identified as the urban systems' spatial features on which to build the most effective strategies of flood management. According to Gourbesville (2012), these strategies usually include both structural measures (for example controlling run-off volume and/or increasing capacity of drainage systems), and non-structural measures, such as spatial planning and building regulations.

1.2. Green infrastructure, Sustainable Urban Drainage Systems (SUDS) and run-off regulation

Ecosystem services for water-flow regulation are the underpinning elements of developing innovative drainage-related concepts, which are placed in the encompassing framework of the green infrastructure planning. Green infrastructure is defined as 'all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales' (Tzoulas et al., 2007). Thus, the concept of green infrastructure goes traditionally beyond storm-water management (Fletcher et al., 2014) and is becoming a keystone around which policy and planning are integrated for landscape multi-functionality (Mell, 2008; La Greca et al., 2011).

A number of researches and practises worldwide coined a range of words and expressions to specifically refer to the development of storm-water management related approaches, such as Low Impact Development in North America, Water Sensitive Urban Design in Australia and Sustainable Urban Drainage Systems (SUDS) in the UK (Fletcher et al., 2014).

The combination of structural and non-structural measures to mitigate urban flooding (Mascarenhas and Miguez, 2002; Gourbesville, 2012) might be able to reduce the impact of urbanization by improving resilience to change in the hydrological cycle, enhancing infiltration and water storage by both creating multifunctional landscapes and regulating construction standards (Barbedo et al., 2014). In particular, among alternatives characterizing the design for resilient flood management, the adoption of solutions like SUDS can re-balance the relationship between the built and not-built components of urban environments (Lennon et al., 2014).

Specifically, SUDS consist "of a range of technologies and techniques used to drain storm-water/surface water in a manner that is more sustainable than conventional solutions" (Fletcher, 2014). They are based on the philosophy of mimicking the natural pre-development site hydrology and follow the principles and goals of low impact development (Ahaiblame, 2012; Fletcher et al., 2014). Examples of these techniques include green roofs, permeable surfaces, infiltration trenches, filter drains and filter strips, swales - shallow drainage channels, detention basins and purpose built ponds and wetlands (Woods-Ballard et al., 2007).

Conventional techniques collect and channel water out of the catchment as fast as possible through structural storm-water conveyance systems (channels, pipes, pumps, regulators and end of pipe solutions) to the outlet of a drainage area. On the contrary, SUDS aim at keeping water onsite as much as possible using landscape features and natural processes (Ahaiblame, 2012).

Both conventional "grey" adaptation measures (EEA, 2012) and SUDS measures can be implemented to manage urban flooding. In spite of being designed to be effective, grey measures are mono-functional, whilst SUDS measures play different roles in the adaptation process (Gill et al., 2007) by producing significant co-benefits and facing negative effects of soil sealing on storm-water run-off (Voskamp and Van de Ven, 2014), such as the increase of the amount and speed of run-off (Scalenghe and Marsan, 2009). At a particular site, SUDS are designed for return periods usually lower than 10 years, to manage the environmental impacts resulting from urban run-off and to enhance, wherever possible, the overall environmental conditions. Thus, their objectives are "to minimize the impacts from the development on the quantity and quality of the run-off, and to maximize amenity and biodiversity opportunities" (Woods-Ballard et al., 2007). In fact, the benefits of these measures lie in the variety of ecosystem services they can supply, along with the water-flow regulating service: they specifically slow water down before it enters a watercourse, providing infiltration, filtration, onsite storage, detention and evapotranspiration (susDrain and CIRIA, 2012).

The shift to an ecosystem-based urban drainage approach that integrates vegetation for water management (Ellis, 2013), becomes of major importance to elaborate planning strategies aimed at restoring or creating a more naturally-oriented water cycle (Lawson et al., 2014).

This paper evaluates the role of SUDS in increasing the water-flow regulation service in a highly urban catchment. A comparison between scenarios of *pre-implementation* and *post-implementation* of SUDS is carried out through catchment simulations. In particular, an indicator to be used as a proxy of regulating service capacity is proposed and tested in a dense urban context of the city of Avola, in Southern Italy.