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Soil sealing and flood risks in the plains of Emilia-Romagna, Italy

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ABSTRACT

Study region: The plains of Emilia Romagna, Italy.
Study focus: Urban expansion is among the main causes of increase in flood frequency and intensity in small rural catchments in Europe, and our study region is paradigmatic in this respect. We present here a regional screening-level assessment of soil sealing impacts in terms of increased flood peak discharges and flooding volumes on the secondary drainage network of the plains. We estimate flood peak discharges and flooding volumes through a simple kinematic model with runoff coefficients for the land use of 2008 and 1976. Additionally, we calculate an equivalent compensatory flood detention volume that would enable preserving flood peak discharges as prior to soil sealing (principle of "hydraulic invariance"). The proposed approach is simple and readily applicable to any region facing similar issues, for screening-level assessment of flood hazards over an extended stream network.
New hydrological insights for the region: The analysis highlights a significant increase in flood hazards throughout the secondary stream network. The impact. Widespread and relatively uniform, is more apparent in smaller catchments and in the case of more permeable soils. This demands retrofitting of the majority of the drainage network and/or significantly higher costs from flooding damages. The analysis suggests that costs of additional flooding after soil sealing may be higher than those of soil sealing impacts compensation through flood detention (hydraulic invariance).

1. Introduction

Soil sealing is the permanent covering of the land surface by buildings, infrastructures or any impermeable artificial material. It has been identified as a major threat in the Soil Thematic Strategy of the European Commission (European Commission, 2006), both in terms of permanent loss of soil as a resource and for its important impacts on soil functionality. A review by Scalenghe and Ajmone Marsan (2009) summarizes the relevance of soil sealing as an impact pathway of human activities on the environment. The importance of soil sealing in urban areas is perceived as a driver of flood risks in many contexts (see e.g., Pitt, 2008; Malucelli et al., 2014).

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In a recent Staff Working Document of the European Commission, the amount of land take for urban development at EU scale is estimated at about 1000 km^2 per year (European Commission, 2012), causing serious concerns. In the same document, guidelines on best practices are presented based on the concepts of limiting soil sealing, whenever possible; mitigating the impacts on soil and soil functions, where new constructions are unavoidable; or compensating with measures directed to improve soil functionality and environmental services in areas where convenient (e.g., de-sealing sealed surfaces, or rehabilitating degraded areas). The relevance of soil sealing effects on floods has been highlighted in several cases (e.g., Nestroy, 2006; Verbeiren et al., 2013; Du et al., 2015). Recent floods throughout Europe have raised societal concerns around the issue of land take by urban expansion, which can significantly increase peak discharges and inundation volumes especially in smaller catchments with artificial drainage networks. Most of these networks were originally designed for land reclamation in agricultural catchments: as damages to agricultural land induced by floods with high return periods might be acceptable compared to the costs of larger hydraulic works, drainage used to be sized to convey a discharge of relatively short return period.

Among others, the Northern Italian region of Emilia Romagna has assisted to a significant expansion of urban areas over the last four decades.

During flood events occurring regularly in the last 20 years, the artificial drainage network was often loaded with increased discharges due to the significant proportion of land turned from agricultural to urban; at the same time, flooding caused more relevant damages as settlements are typically more vulnerable than simple agricultural land. A paradigmatic event occurred in October 1996 when, following an approximately 100-year return period rainfall of around 200 mm in two days, almost a third of the plains in the region were flooded due to insufficiency of the local drainage networks. This event uncovered how the development of urban areas in the years 1970–2000s had generated massive costs for the retrofitting of the drainage network, and triggered response from planning, accelerating the development of river basin scale flood management plans (e.g., Autorità dei bacini regionali romagnoli, 2001) as prescribed by the Italian legislation of the time, later aligned with the European Floods Directive (European Commission, 2007).

Understanding the distribution and intensity of soil sealing impacts on flood hazards is key to management.

In this paper, we focus on the secondary drainage network in the plains of Emilia Romagna, in most cases made of artificial or highly trained channels, with a catchment area below 100 km^2. Building on previously published work on the impact of soil sealing on flood runoff coefficients (Ungaro et al., 2014), we calculate conventional potential inundation volumes as an indicator of flood risk specifically due to soil sealing by urban land take, without detailed modelling of the stream network, and a complementary indicator given by the equivalent flood detention volumes required to keep peak discharges after land take to the levels prior to land take. These indicators allow understanding the extent, distribution and magnitude of flood hazards arising from soil sealing.

2. Materials and methods

2.1. Study area

Emilia Romagna (latitude 43°50′N–45°00′N; longitude 9°20′E–12°40′E Greenwich, approximately) is a region in Northern Italy with a total area of 22,124 km^2. The main agricultural area, covering slightly more than half of the region (12,000 km^2), is the continuous plain stretching south of the Po river and delimited by the Apennines range on the south and by the Adriatic sea on the east (Fig. 1). Maximum and minimum average annual temperature are 19.3 and 8.2 °C, respectively; mean annual precipitation ranges from 520 to 820 mm. The soils of the area, mainly on quaternary alluvial deposits, are characterised by a high degree of heterogeneity. For this study, we used a map of "soil functional groups" (Guermandi and Tarocco, 2007), where the 237 Soil Typological Units of the 1:50,000 soil map (Regione Emilia-Romagna, 2005) are aggregated according to the top-soil textural family, drainage class, slope, presence of horizons with organic carbon >2.5%, and flooding occurrence (see Supporting information – SI; Guermandi and Tarocco, 2007).

The soils of the Emilia Romagna plain still sustain intensive agricultural productions, mainly consisting of rotating arable crops (cereals, pulses, and forage), orchards and vineyards, even if in the period 1954–2003 agricultural land decreased of about 1200 km^2 mainly due to urbanisation (Di Gennaro et al., 2010). Between 1976 and 2008, the two reference periods considered in this study, urban and industrial areas have increased of about 1000 km^2 (Regione Emilia Romagna, 2011a,b; Malucelli et al., 2014 – see SI). For the implementation of the Water Framework Directive (WFD) 60/2000/EC and the Flood Directive 60/2007/EC, the region belongs to the Po river basin district in its western part, and to the Northern Apennines river basin district in its eastern part. The former is administered by the Po river basin district authority, and the latter directly by Regione Emilia Romagna government with the support of the three River basin authorities of the Reno, the Marecchia and the Romagna (including Lamone, Fiumi Uniti, and Savio) catchments, respectively, see Fig. 1.

2.2. Incremental inundation volumes

For the present analysis, we assume that the drainage network can safely convey a design discharge of 20 years return period, as estimated at the time of design (mostly, pre-World War II) reflecting approximately the level of sealing in 1976. Although a crude simplification, this is a condition representative of the typical hydraulic performance of drainage networks for land reclamation in the region. We may consequently assume that, for a higher return period T and for the level of sealing