Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Defining context-specific scenarios to design vegetated buffer zones that limit pesticide transfer via surface runoff

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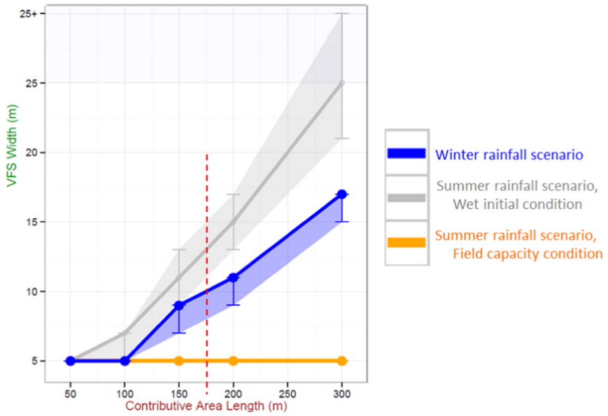
HIGHLIGHTS

- A method and its associated tools for sizing VFS using process-based modeling.
- Method which relies on the local agro-pedo-climatical VFS context, relevant for a wide range of pesticides
- First time that a sizing method explicitly takes into account a shallow water table presence
- Application on a small agricultural watershed, which gives relevant results
- Elaboration of nomograms, easier to use even in the field

GRAPHICAL ABSTRACT



Example of a buffer sizing nomogram, depending on the contributing area length, for 70% retention efficiency. Each color stands for a climatic scenario (defined by rainfall event and soil initial humidity status). Each curve shows the result for a contributive area slope of 5%, the shallow zone corresponding to a slope varying from 2 to 10%. For example, for a contributive area 175 m long, the VFS should be 13 m wide to infiltrate 70% of the incoming water during the summer rainfall occurring on a wet contributive area.

ARTICLE INFO

Article history:
Received 5 July 2016
Received in revised form 13 September 2016
Accepted 13 September 2016
Available online xxxx

Keywords:
Vegetative filter strip
Buffer zone modelling
Process-based model
VFS sizing
Shallow water table
Watershed

ABSTRACT

When used in addition to environmentally friendly cultural practices, buffer zones can limit the water transfer of pollutants, in particular pesticides, towards water resources. The choice of the buffer zones' type and positioning, considering water pathways and flow components, is crucial. When this choice has been performed, buffer zones dimensions must still be optimized, according to the environment characteristics, which strongly influence their effectiveness. This article presents a method and its associated tools, including VFSMOD model, which aim at optimizing vegetative buffer zones (VFS) sizes, by simulating their transfer mitigation effectiveness. A first application of this methodology is illustrated on a small agricultural watershed in Brittany. A second application, based on the simulation of a large number of scenarios, leads to the elaboration of nomograms. They allow optimizing VFS size in a simpler way from the user's point of view.

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http://dx.doi.org/10.1016/j.scitotenv.2016.09.105
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Please cite this article as: Carluer, N., et al., Defining context-specific scenarios to design vegetated buffer zones that limit pesticide transfer via surface runoff, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.09.105

1. Introduction

Diffuse pollution (nitrates, phosphates, suspended matter, pesticides, and metals) has a significant effect on water resources. These contaminants are likely to harm the ecological quality of waterways and to compromise capacities to meet the "good ecological status" ambitious target set in 2015 by the WFD (Water Framework Directive). They may also compromise the drinking water supplies of populations and necessitate the use of expensive treatments to reach drinking water standards. For plant protection products, it is necessary to act at several levels to minimize non-point pollution: limiting their use and preventing and limiting their transfer from agricultural fields to water resources. Regarding this solution, vegetative buffer zones (grass strips, wood, riparian forests, etc.) are considered to be the most efficient buffers for pollutants transported mainly through surface runoff and sediment, by enhancing the retention and degradation of active substances (e.g., Poletika et al., 2009; Reichenberger et al., 2007). However, several factors related to topographical features and agricultural practices can affect vegetative filter zones (i.e., vegetative filter strips (VFSs)), determining their performance and limiting their effectiveness: to be efficient, they must be correctly designed in consideration of their positioning (Tomer et al., 2008), type, and size (Daniels and Gilliam, 1996; Dosskey, 2002, Dosskey et al., 2011). Furthermore, fixed VFS widths do not prevent water, sediment and pesticide transfer, as surface runoff is never spatially uniform on a field given heterogeneities of topographical and soil characteristics (Beven et al., 1988).

For VFS sizing, a field diagnosis must be performed, ideally at the watershed scale, to identify the main potential sources and pathways of contamination. It should be based on soil characteristics, crops, cultural practices, topographical features and observed runoff pathways. It is then possible to determine which mitigation solutions to adopt and to select appropriate VFS sizes and positions when this choice is relevant (Bernard et al., 2014, *in French*). The first solution for VFS sizing involves using field expert knowledge or recommendations from national or local institutions, functioning in a given context (e.g., CORPEN/Cemagref in France and the USDA in the US). Yet conditions that influence pollutant retention through a buffer (e.g., soil, slope, and hydrology) can differ substantially from one location to another (Lowrance et al., 2000; Dosskey et al., 2006), and pollutants do not behave similarly in buffer soils, as a function of their physico-chemical properties. This is why simple laws cannot represent the diversity of soil, agronomic, climatic and chemical scenarios. More deterministic methods can then be used (e.g., abacus or "decision rules" developed for some specific watersheds) via physical modelling depending on soil survey attributes (mainly slope, soil and rainfall factors) (e.g., Dosskey et al., 2006). A physical approach to sizing vegetated buffers involves directly applying a physical model that is specifically parameterized to a given local context. The Vegetative Filter Strip MODel VFSMOD (Muñoz-Carpena et al., 1999) is a vegetative filter strip physically based model that can be applied directly as a VFS sizing tool either for one given VFS location (Dosskey et al., 2006, 2008, 2011) or at a larger scale by coupling it to a watershed model (White and Arnold, 2009) or to GIS tools (e.g., Park et al., 2013). This tool, however, must be properly parameterized to determine local characteristics of flow entering a filter as well as rainfall typical events, initial conditions, soil characteristics, and buffer properties. The method proposed by Dosskey et al. (2008, 2011), which involves using soil surveys to determine widths of filter strips based on laws of VFSMOD simulations, is currently the most appropriate approach available, as it is physically based but also simple enough to be used in an operational context. However, the method can be applied and tested for sediment reduction only and not to examine pesticides, and the authors note several limitations to their method: the Green-Ampt solution used in the VFSMOD does not allow one to examine conditions wherein a VFS is bounded by a shallow (perched) water table. This boundary condition can severely limit VFS infiltration capacities by causing runoff by saturation. This is an important restriction, as VFSs can be located in an area where a shallow impermeable soil layer can form perched water tables and also because VFSs are often located along river networks, increasing the probability of shallow river connection formation (Reichenberger et al., 2007; Lacas et al., 2012). The latest version of VFSMOD (Muñoz-Carpena et al., submitted for publication) simulates infiltration under shallow water table conditions. Other limitations of Dosskey et al.'s (2008, 2011) method concern infiltrated pollutants, for which behaviour in soil is not represented by VFSMOD. However, a model representing pollutant transport through soil would need to represent lateral transfer and chemical reactions, adding a large set of input parameters. It would thus likely lose operational properties that allow non-modellers to use this method. In this study, we propose a new method that improves modelling scenarios and their applicability in the field though physical basis. Scenarios take into account initial states of humidity and water table effects on VFS infiltration. The proposed method is then based on (i) the quantification of water flows produced by the contributing area and (ii) VFS capacities to infiltrate incoming flows.

We first briefly review the main physical processes that occur in a VFS to properly apply the method. The method then is presented and applied to a test catchment in north-western France. Our construction of nomograms from a large sample of simulated scenarios is then described as a method to be used by non-modellers.

2. Physical processes of a vegetative buffer zone

The contributive area of a buffer zone is defined as the part of a watershed where flows entering the buffer zone are generated. Incoming surface runoff on a buffer zone is very sensitive to contributive area extension and characteristics. Consequently, it is important that the sizing step occurs after diagnosis at the watershed level to ensure that the nature of the buffer zone and its positioning are relevant in consideration of environmental conditions. Ideally, buffer zone implementation should occur at the catchment scale for optimal sizing.

2.1. Water flow components within a buffer zone

Water flows into and on the ground through the following three main pathways: infiltration and deep percolation, shallow subsurface lateral flow, and surface runoff. This article focuses on dry buffer zones, which are mainly of relevance to the latter mode of circulation. We distinguish here between "dry" buffer zones where soil surfaces are not supposed to be durably ponded (grass strips, wood, riparian forests, etc.) and "wet" buffer zones where major dissipating processes are linked to wet conditions (artificial wetlands). Surface runoff can be generated when rainfall rates exceed soil surface hydraulic conductivity so that excess water does not infiltrate, and generate surface flow (Hortonian runoff) or when an entire soil profile becomes saturated with water (before or during an event) so that all incoming water contributes to surface runoff (runoff on a saturated surface). These two main forms of runoff, and Hortonian runoff in particular, can be erosive and can transport fine particles detached from the ground through raindrops or flow. Nevertheless, erosion is not systematic when runoff occurs, and especially when simplified cultural practices are used and when soil is rich in clay or organic matter.

2.2. Key drivers of vegetative buffer strip efficiency

Three features allow buffers to reduce runoff and retain pesticides (see Fig. 1). VFS soil permeability is higher than that of cultivated plot permeability due to the significant root density of grass cover of the former (the existence of a root mat, i.e., a dense layer rich in fine living and dead roots, linked to the presence of permanent vegetation in the upper ten centimetre layer of soil). This high infiltration capacity usually reduces incoming water flows significantly. A second property is high roughness due to the density of the aerial component of vegetation.

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