Catena 149 (2017) 120–130

Contents lists available at ScienceDirect

Catena

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

A modelling framework to simulate river flow and pesticide loss via preferential flow at the catchment scale

M.L. Villamizar *, C.D. Brown

Environment Department, The University of York, Heslington, York YO10 5NG, UK

ARTICLE INFO

Article history:
Received 22 September 2015
Received in revised form 15 August 2016
Accepted 9 September 2016
Available online xxxx

Keywords:
Pesticide
Preferential flow
MACRO
SPIDER
In-stream
Catchment

ABSTRACT

A modelling framework with field-scale models including the preferential flow model MACRO was developed to simulate transport of six contrasting herbicides in a 650 km^2 catchment in eastern England. The catchment scale model SPIDER was also used for comparison. The catchment system was successfully simulated as the sum of multiple field-scale processes with little impact of in-stream processes on simulations. Preferential flow was predicted to be the main driver of pesticide transport in the catchment. A satisfactory simulation of the flow was achieved (Nash-Sutcliffe model efficiencies of 0.56 and 0.34 for MACRO and SPIDER, respectively) but differences between pesticide simulations were observed due to uncertainties in pesticide properties and application details. Uncertainty analyses were carried out to assess input parameters reported as sensitive including pesticide sorption, degradation and application dates; their impact on simulations was chemical-specific. The simulation of pesticide concentrations in the river during low flow periods was very sensitive to uncertainty from rain gauge measurements and the estimation of evapotranspiration.

1. Introduction

Modelling the fate of pesticides at the catchment-scale is an important tool for pesticide management to gain insight into behaviour at this scale and to evaluate the impact of different management practices. Pesticide loss through subsurface drainage (when tile drains are present) is a dominant route for pesticide transport to surface waters with surface runoff also locally important (Harris and Catt, 1999; Johnson et al., 1996). Heavy clay soils with artificial drainage frequently exhibit pesticide transport via preferential flow, causing surface water contamination (Brown et al., 1995; Johnson et al., 1996).

The model of water flow and solute transport in macroporous soil, MACRO (Jarvis et al., 1991), is the most widely used preferential flow model at the field scale in Europe. A few studies have applied field-scale models in catchment modelling by considering that the fate of pesticides in the catchment would be the result of the sum of multiple field-scale processes (Lindahl et al., 2005; Tediosi et al., 2013). Monitoring studies of diffuse water pollution by pesticides at different hydrological scales have shown that pesticide losses normally occur as pulses of fluctuating concentrations with similarities in their pattern; thus, patterns (but not magnitude) of concentrations measured in a small receiving water body adjacent to an arable field are broadly conserved in terms of the timing and duration of peaks when the same pesticide is monitored further downstream (Brock et al., 2010). These patterns of peak concentrations are largely dependent on rainfall behaviour, suggesting that processes occurring within the river network may not be a major influence on the timing and magnitude of peak pesticide concentrations in surface waters at larger scales.

Coupling fate models involves combining more than one model in order to establish a modelling framework that can simulate a broader system than can any of the component models in isolation (Zhu et al., 2013). In this paper a modelling framework was developed by combining hydrological and fate models in an attempt to simulate various pathways of water flow and their associated pesticide losses in the Wensum catchment in the eastern region of the UK. The Wensum is one of the six priority catchments in England and Wales targeted under the Catchment Sensitive Farming programme (CSF), to reduce diffuse water pollution by pesticides. Regular pesticide monitoring has been undertaken since 2006 to evaluate the effectiveness of the management actions. The modelling framework using MACRO aimed to test whether the catchment system can be simulated as the sum of multiple field-scale processes.

The catchment scale model SPIDER is a preferential flow model that simulates hydrological flow and pesticide fate in small catchments (Renaud et al., 2008). In contrast to field-scale models like MACRO, SPIDER considers spatial variability of soils, crops and pesticide usage in the catchment to simulate the effect of the transport and sorption of pesticides in the river network. SPIDER was also applied to the Wensum to compare results from a catchment model to the modelling framework using a field-scale model.

* Corresponding author at: Environment Department, University of York, Wentworth Way, Heslington, York YO10 5NG, UK.
E-mail addresses: martha.villamizarvelez@york.ac.uk, marthaluvv@gmail.com (M.L. Villamizar).

http://dx.doi.org/10.1016/j.catena.2016.09.009
0341-8162/

Despite the importance of uncertainty analyses, very few pesticide modelling studies include them in their results. Physically-based hydrological and pesticide transport models require a large amount of input data from the study area that are not always known with certainty (Sohrabi et al., 2002). Depending on the level of accuracy needed and the sensitivity of the model, parameters can be left at their default values, taken from databases, derived from empirical equations or estimated using expert judgment; any of these procedures will introduce uncertainty into the model, in addition to the simplification of the physics and processes by a model conceptualisation (Dubus et al., 2003). These uncertainties are responsible for reducing the predictive capacity of the simulation, providing results that differ from reality. In addition, different sources of uncertainty can magnify the overall uncertainty of the outputs (Zhang et al., 1993). An uncertainty analysis of key sources of uncertainty in the input parameters was also included to assess their impact on model simulations.

2. Methods

2.1. Site description and data acquisition

The Wensum catchment is located in the eastern region of the UK, to the north west of Norwich and covers an area of approximately 650 km^2. The River Wensum flows approximately 78 km through the county of Norfolk from Colkirk Heath to its confluence with the River Yare in Norwich (Fig. 1). The monitoring point located at Sweet Briar Road Bridge (National Grid Reference: TG 206 095) defined the simulated catchment. Slowly permeable soils with tile drainage systems located on the river valley (Beccles and Burlingham associations) constitute the main soils in the catchment (Hodge et al., 1984), accounting for 57% of the catchment area. At the top of the catchment, the soils are a combination of well-drained loamy soils (Barrow) with patches of sandy soils (Newport), whilst the Newport association predominates at the base of the catchment. The floodplains are dominated by peaty soils (Adventurers) and loamy and sandy soils with naturally high groundwater and peaty surface layers (Isleham). Meteorological data from the closest stations to the catchment were used including Norwich Airport (hourly rainfall), Wattisham (hourly solar radiation and daily maximum and minimum temperature) and Marham (hourly wind speed and vapour pressure) (Fig. A–1).

Physicochemical properties of the pesticides used in the models were taken from typical values reported in the literature (Table A–1). Reported mean values of the soil-water partition coefficient normalised to soil organic carbon content (K_{oc}) were used in the model; the exception was for propyzamide where the reported K_{oc} was very large (840 ml g^{-1}). Pedersen et al. (1995) reported soil-water partition coefficient (K_d) values for various soils with different organic carbon contents. Based on the organic carbon content of Beccles (1.7%) and Burlingham (1.4%), K_d values of 4.96 and 4.09 ml g^{-1}, respectively, were estimated by extrapolation of the reported data. These K_d values correspond to an average K_{oc} value of 292 ml g^{-1} that was then used in the model to improve the simulation of propyzamide.

The simulated crops were winter wheat (WW) and oilseed rape (OSR) as they are the main crops present in the catchment and all of the pesticides simulated are applied to one or both crops. Generic crop parameters were taken from FOCUS (2000) Châteaudun scenario, except for dates of growth stages for WW which were modified to agree with typical growing information for the UK. Crop areas (Table A–2) and pesticide usage (Table A–3) reported biannually by crop and pesticide type as the total area treated with pesticide (in ha) and total pesticide weight applied (in kg) for the Eastern region were used to determine the proportion of crop area treated with pesticides and the application rates by assuming that the usage in the catchment would match that in the region. Dilution from untreated areas was implicitly included by calculating average application rates for the whole catchment for each of the pesticides simulated.

Measured data on water flow and pesticide concentrations in the River Wensum used for the model evaluation were supplied by the Environment Agency of England and Wales. Water flow was measured at the gauging station at Sweet Briar Bridge with 15-min resolution and reported as daily mean flow. The frequency of water samples collected for pesticide analysis varied during the year but was usually twice a week (CSF, 2012). Grab water samples were also collected at Sweet Briar Road Bridge and sent for analysis by the UK National Laboratory Service using accredited methods developed to analyse suites of pesticides in natural waters. Table A–4 shows the limit of quantification for each pesticide as these changed during the studied period.

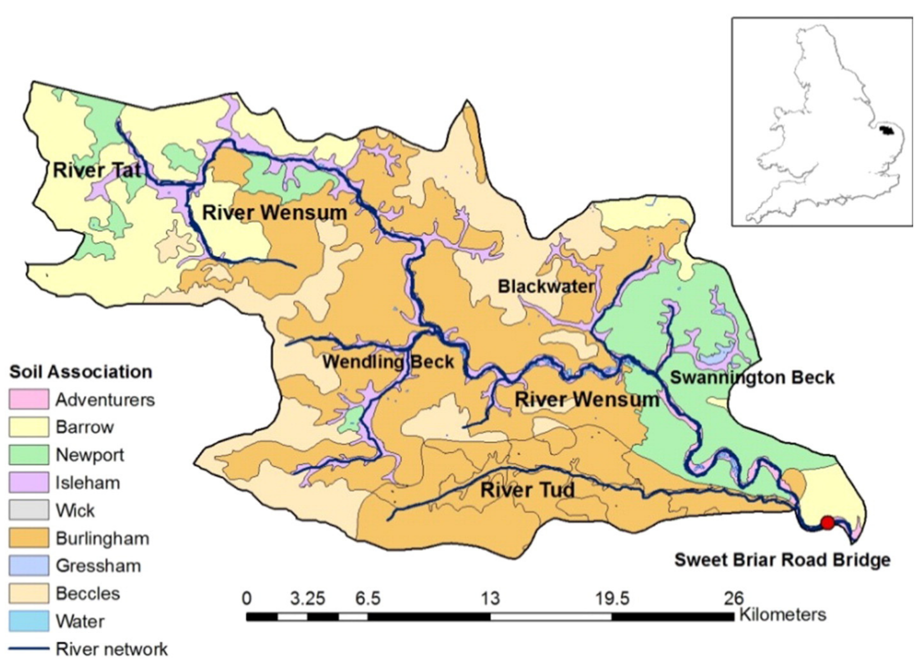

Fig. 1. Wensum catchment showing the river network and the catchment outlet at Sweet Briar Road Bridge. Inset: location of the Wensum catchment within England and Wales.