Water Research 102 (2016) 607–618

Contents lists available at ScienceDirect

Water Research

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

Predicting runoff induced mass loads in urban watersheds: Linking land use and pyrethroid contamination

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ARTICLE INFO

Article history:
Received 19 February 2016
Received in revised form
16 June 2016
Accepted 17 June 2016
Available online 22 June 2016

Keywords:
GIS
Pyrethroids
Land use
Ballona Creek Watershed
Stormwater
Policy

ABSTRACT

Pyrethroid pesticide mass loadings in the Ballona Creek Watershed were calculated using the volume-concentration method with a Geographic Information Systems (GIS) to explore potential relationships between urban land use, impervious surfaces, and pyrethroid runoff flowing into an urban stream. A calibration of the GIS volume-concentration model was performed using 2013 and 2014 wet-weather sampling data. Permethrin and lambda-cyhalothrin were detected as the highest concentrations; deltamethrin, lambda-cyhalothrin, permethrin and cyfluthrin were the most frequently detected synthetic pyrethroids. Eight neighborhoods within the watershed were highlighted as target areas based on a Weighted Overlay Analysis (WOA) in GIS. Water phase concentration of synthetic pyrethroids (SPs) were calculated from the reported usage. The need for stricter BMP and consumer product controls was identified as a possible way of reducing the detections of pyrethroids in Ballona Creek. This model has significant implications for determining mass loadings due to land use influence, and offers a flexible method to extrapolate data for a limited amount of samplings for a larger watershed, particularly for chemicals that are not subject to environmental monitoring. Offered as a simple approach to watershed management, the GIS-volume concentration model has the potential to be applied to other target pesticides and is useful for simulating different watershed scenarios. Further research is needed to compare results against other similar urban watersheds situated in mediterranean climates.

1. Introduction

Residential and urban areas are commonly sprayed for pest control, which includes the application of the insecticide, synthetic pyrethroids (SPs). In multiple studies, SPs have been detected in urban water ways (Ding et al., 2010; Hintzen et al., 2009; Kuivila et al., 2012; Li et al., 2013; Liu et al., 2004; Mehler et al., 2011; Wang et al., 2012; Weston et al., 2011) with evidence of toxicity exceeding threshold levels for sensitive, benthic invertebrates (Amweg et al., 2006; Bay et al., 2010; Delgado-Moreno et al. 2010, 2011; Lao et al., 2010). Moreover, urban (Domagalski et al., 2010; Ensminger et al., 2013; Jorgenson and Young, 2010; Weston and Lydy, 2010) and residential areas (Bay et al., 2010; TDC Environmental, 2005; Weston et al., 2009; Wilen et al., 2005) have been implicated as the source of SP contamination. In climates often considered mediterranean, usage of pyrethroids and pesticides have increasingly polluted regional river and freshwater bodies through urbanized settlements and crop production (López-Doval et al., 2013). For instance, SPs enter surface waters primarily during storm-water discharge (Jorgenson et al., 2013; Weston et al., 2005; Weston and Lydy, 2010) in such climates characterized by alternating rainy seasons and droughts (Lee et al., 2004). SPs are transported mainly adsorbed to suspended solids, and secondarily, in association with dissolved organic carbon (DOC) (Weston and Lydy, 2012), which contributes to SP transport in urban waterways to downstream water bodies during storm events (Amweg et al., 2006). Because these recent studies reveal that SPs transfer from impervious surfaces, and impair urban water bodies that are

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http://dx.doi.org/10.1016/j.watres.2016.06.040
0043-1354/

Abbreviations

BC	Ballona Creek
BCW	Ballona Creek Watershed
CDPR	California Department of Pesticide Regulation
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
EMC	Event mean concentration
GIS	Geographic Information Systems
PUR	Pesticide Use Database (CDPR)
RC	Runoff coefficient
SCAG	Southern California Association of Governments
SMB	Santa Monica Bay
SP	Synthetic pyrethroid
TOC	Total organic carbon
UBC	Upper Ballona Creek
UBCW	Upper Ballona Creek Watershed
USGS	United States Geological Survey
WOA	Weighted Overlay Analysis

particularly susceptible to SP runoff during rainy seasons such as in mediterranean climates, there is an urgent need for simple stormwater modeling to estimate stormwater pollution for SPs and avert the potential environmental costs associated with SP contamination.

Research has linked the transport of synthetic pyrethroids from residential areas in urban systems (Hintzen et al., 2009; Jiang et al., 2012) with storm events where SPs can sorb to soils, sediment, and DOM and potentially cause downstream contamination. It is widely suspected that DOM likely increases the distribution of non-polar SPs from the sediment to facilitate transport within Ballona Creek (Delgado-Moreno et al., 2010). DOM has the ability to associate with hydrophobic molecules such as SPs in natural water systems, thereby reducing their uptake by sediment (Suffet et al., 1982). This finding is in agreement with DOM-bound chemicals becoming mobile, which may subsequently equilibrate and become partially solubilized as free pesticides at downstream locations where they can become bioavailable.

Several studies have used stormwater watershed modeling to predict pyrethroid contamination in waterways and sediment from storm events, linking SP contamination to land use. To observe the multiple processes that include pesticide buildup and the contributing effects that influence wash off, Luo et al. (2013) developed a four-pool conceptual model that could be used to predict pyrethroid wash off potentials from concrete surfaces. Jorgenson et al. (2013) developed a screening-level exposure model to predict that toxic unit exposure was related to the synthetic pyrethroids from urban stormwater discharge. Luo and Zhang's (2011) hybrid PRZM-GIS watershed model correlated sediment toxicity to SP contamination using Geographic Information Systems (GIS) map layers to simulate agricultural landscape characteristics. GIS modeling has also used to isolate high pyrethroid runoff specific areas within an agricultural watershed (Zhang et al., 2008), and identified potential pyrethroid emission hot spots to analyze for water and soil contamination in the European continent using Eurostat database on pesticides and land cover classes from the Corine Land Cover 2000 map (CLC2000) (Pistocchi et al., 2009). While these valuable studies predicted SP contamination on a watershed-scale based on agricultural and urban land use to estimate SP pollutant loads in streams, they do not differentiate between the specific areas within an urban watershed that produce the most mass loadings within an urban environment, nor do they offer a simple GIS-based model that can evaluate multiple SP mass input scenarios. Because urban systems have been increasingly associated with SP contamination in urban creeks and sediments, this study concentrates on the different land uses within an urban watershed.

The goal of this project is to predict SP mass loadings into watershed runoff using a customized GIS modeling and the volume-concentration method of Park et al. (2009). Specifically, this study focuses on whether impervious surfaces in Upper Ballona Creek Watershed (UBCW) show higher SP mass loadings from SP applications and if the water-phase concentration of synthetic pyrethroids (SPs) can be calculated from the reported usage. As a secondary interest in this study, SPs from residential, commercial, industrial, or public land uses or residential/commercial land uses are evaluated to see if severely limiting SP land use emissions can result in a significant (80%) reduction in SP mass loadings into Upper Ballona Creek (UBC). To validate the results, a comparison of predicted mass loading was made to the total measured SP mass from field sampling during two storm events in 2013–2014. The results were also compared to sales records and usage reports of the target SPs in the study area.

2. Materials and methods

2.1. Study area

This study was conducted in the Ballona Creek Watershed, in Los Angeles, California, which initially had not been sampled for synthetic pyrethroid water concentrations. The State Water Resources Board Surface Water Monitoring Program (Phillips et al., 2014) has, however, periodically monitored SP sediment contamination, and the California Department of Pesticide Regulations (CDPR) recently established a monitoring site at Centinela Avenue for Ballona Creek in their Study 270 (2014–2015) (Budd, 2014). Ballona Creek has already been identified as a major source of pollutants for Santa Monica Bay as a result of untreated stormwater runoff being received into estuary and bay, and the concrete channelization of Upper Ballona Creek (Curren et al., 2011; Wong et al., 1997).

Ballona Creek emerges from a series of underground drains and continues for 16 km as an open channel from south of Hancock Park in Los Angeles through Culver City, where it merges with Sepulveda Channel and Centinela Creek, eventually discharging all watershed runoff into Santa Monica Bay at Playa del Rey (Fig. 1). The Upper Ballona Creek Watershed (UBCW) is a concrete lined ephemeral creek and storm drain that covers approximately 255 km^2 of mostly residential and vacant land spaces in the western portion of the Los Angeles Basin (Curren et al., 2011; Wong et al., 1997). Ballona Creek (BC) itself is a flood-control channel (Bay et al., 2010), and was designed to reduce flooding in the Los Angeles urban environment. UBCW is 65% impervious for the entire watershed (Curren et al., 2011; Lao et al., 2010; Park et al., 2009), however, for the land uses that were considered for this study, UBCW is considered 51% impervious. The City of Los Angeles' storm water collection station is located downstream of Ballona Creek and demarcates the bottom of the Upper Ballona Creek Watershed, which is above tidal influence. In previous studies, research groups at UCLA have conducted research on UBCW (Curren et al., 2011; Park et al., 2009; Wong et al., 1997). In comparison, Bay et al. (2010) and Lao et al. (2010) conducted research on pyrethroids in Ballona Creek Estuary (BCE), however, UBC was excluded from the analysis.

The mean annual rainfall in Los Angeles is between 300 and 380 mm (McPherson et al., 2005; SMBRC, 2010). Having a mediterranean climate, the local area is characterized by limited rainfall with the wet-season occurring primarily between the months of