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Study 276: Protocol to Model Pesticide Runoff on Impervious Surfaces at Residential-Lot Scale

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1. Introduction

Environmental monitoring studies have shown that urban pesticide applications result in potentially toxic surface water runoff in California and other States (Amweg *et al.*, 2006; Ding *et al.*, 2010; Hintzen *et al.*, 2009; Holmes *et al.*, 2008; Weston *et al.*, 2009; Weston *et al.*, 2005; Weston and Lydy, 2010). With the discontinued residential use of some organochlorines and organophosphates, use of replacement insecticides such as synthetic pyrethroids and fipronil has increased in recent years (Epstein and Bassein, 2003). For more effective mitigation strategies for urban aquatic environmental protection, there is an urgent research need for improved understanding and prediction of pesticide transport mechanisms over impervious surfaces.

Department of Pesticide Regulation (DPR) has been involved in multiple projects by either surface water monitoring or contracted studies to evaluate urban pesticide use and their contributions to the receiving water problems. These projects are focused on urban pesticide fate and transport mechanisms in various spatial scales, including laboratorial studies for pesticide sorption and desorption (e.g., contracts 05-0108C, 06-0129C; http://www.cdpr.ca.gov/docs/emon/surfwtr/contracts.htm), residential landscape studies for pesticide runoff (e.g., contracts 10-C0085, 10-C0121; http://www.cdpr.ca.gov/docs/emon/surfwtr/contracts.htm), and watershed-scale surface water monitoring for storm flow and baseflow in major urbanized areas (e.g., studies 249, 264; http://www.cdpr.ca.gov/docs/emon/pubs/ehapreps.htm). Currently, most of the projects are conducted independently and their findings may not be readily compatible and transferable within and between the relevant spatial scales. A modeling approach is required to integrate these projects for a better understanding on the transport and exposure of urban pesticides.

According to the recent model review by Cheplick et al. (2006), adequate urban pesticide runoff models do not exist. The urban pesticide modeling domain generally consists of three major components of impervious surface, pervious surface and storm drainage system. In specific, simulation capability of pesticide washoff and runoff over impervious surfaces is not sufficiently covered by the existing models, while processes on pervious surface and in drainage network are satisfactorily predicted by some models, such as Root-Zone Pesticide Model (PRZM) (USEPA,

2006) and Storm Water Management Model (SWMM) (USEPA, 2010), respectively. Due to the lack of a suitable model for hardscape, current approaches generally rely on adapting existing urban catchment-scale storm models or agricultural field-scale runoff models to urban environments. Typically, equations designed for pervious surfaces have been applied, with parameter extrapolation, in the attempts to simulate pesticide runoff from impervious surfaces. Limitations are apparent in these modeling approaches. For example, SWMM simulations are based on continuous accumulation of chemicals (called “pollutant build-up”) on the land surface, rather than actual pesticide applications. In addition, SWMM does not simulate chemical adsorption processes to soil. The primary limitations of PRZM are associated with its modeling dimension (zero-dimensional, or “unit-area” model) and simulation time step (daily).

Therefore, a physically based model is required to simulate pesticide runoff from impervious surfaces at residential-lot scale. The proposed model will represent the unique processes and practices in pesticide application, transport, and mitigation on hardscape surfaces at fine spatial and temporal resolutions. Simulation of hydrology and pesticide behaviors on residential impervious surfaces will be the starting point for future developments of urban pesticide models. Future work may include linkage to models for pervious surfaces, thereby allowing simulation of various physical configurations for at residential-lot scale and urban watershed scale.

2. Objectives

This study is aimed to develop a modeling approach to simulate pesticide runoff from urban impervious surfaces. The specific objectives include: [1] to review existing studies and experimental results on pesticide fate and transport on impervious surfaces for their physical mechanisms and mathematical formulations, [2] to develop a spatially explicit model to predict hydrologic and water quality (pesticides and sediment) processes on impervious surfaces, with a residential driveway as a potential test scenario, and [3] to validate the developed model with pesticide runoff results from plot-scale landscape experiments. The model is anticipated to facilitate scenario analysis on mitigation practices and support further modeling studies at watershed scale.

3. Personnel

This study will be conducted by Environmental Scientist Yuzhou Luo under the supervision of Senior Environmental Scientist Sheryl Gill and the guidance of Research Scientist III Frank Spurlock. Questions concerning this protocol should be directed to the project leader Yuzhou Luo by phone at (916)445-2090 or by email at yluo@cdpr.ca.gov.

4. Study Plan

4.1 Mathematical Formulation for Pesticide Washoff

Pesticide washoff (by desorption and particle detachment) from impervious surfaces into the overlying water layer of overland flow is the essential process in this study. Since modeling studies particularly designed for urban pesticides are not available, this study will start with a comprehensive literature review on urban hydrology, stormwater characteristics, and washoff simulations for general pollutants from impervious surfaces (Burton and Pitt, 2001; Donigian and Bicknell, 2007; Field and Sullivan, 2002; USEPA, 2010). Most of the existing assumptions (e.g., KOC-based partitioning, instantaneous equilibrium) and equations (e.g., soil-layer-based solution extraction, Universal Soil Loss Equation) for agricultural landscape are not applicable to impervious surfaces. A time-dependent sorption-desorption relationship, usually called washoff profile or washoff potential, with adjustments by product formulations and concrete properties will be derived and parameterized for determining pesticide release during overland flow events. The mathematical formulation of pesticide washoff will be evaluated using experimental data from pesticide washoff studies in progress.

4.2 Model Development

The model will describe the generation and 2-dimensional movement of overland flow and associated pesticides (in both dissolved and sorbed phases) over a concrete slope. The simulation domain includes a residential driveway and the overlying shallow water layer of overland flow induced by precipitation and irrigation. The dependent variable is the pesticide concentrations in aqueous and sediment-bound phases in the flow. Three major simulation procedures are proposed in modeling approach:

[1] Simulation of overland flow on the impervious surface under precipitation/irrigation events,
[2] Simulation of pesticide washoff from impervious surface into overland flow, and
[3] Simulation of pesticide fate and transport with the overland flow.

As mentioned before, the essential part in the model development is the component #2, which differentiates the pesticide simulations between impervious and pervious surfaces, and the associated processes that are not completely available in existing models. Components #1 and #3 establishes hydrologic framework for pesticide transport and routing to downstream locations of evaluation. Main physical and chemical processes to be simulated in the model include:

- Hydrography of overland flow, simulated as kinematic wave flow by Saint-Venant's equation (Tayfur *et al.*, 1993) and parameterized by precipitation/irrigation rate and surface characteristics,
- Pesticide adsorption-desorption processes. Washoff profiles will be first developed from reported experimental results, and then incorporated into diffusion-type equations using Fick's law to formulate the bi-directional mass transfer between impervious surface and overland flow,
- Particle transport in overland flow, including formulations of particle detachment and settling, and the carrying capacity of suspended particles, and
- Pesticide transport in overland flow, simulated by a convection-diffusion equation that includes degradation processes.

Two characteristics of pesticide transport from impervious surfaces and their modeling implementations will be investigated in this study. The first one is about the availability or transferability of adsorbed pesticide on the impervious surface to runoff extraction. Unlike applications to the soils, only a small portion of applied pesticide on concrete can be extracted by overlying water flow even immediately after the treatment. In addition, the availability might be associated with various factors such as the days after application (DAA), pesticide formulation, surface conditions, rainfall intensity, and runoff duration (Jiang, 2011; Jorgenson and Young, 2010). The other modeling highlight is the importance of particles on the pesticide transport on impervious surface. Although impervious surfaces are characterized with a low erodibility, results of field experiments indicated that majority of pyrethroid offsite transport from concrete are associated with suspended solids (Jiang, 2011). The partitioning pattern of urban pollutants in dissolved and adsorb phases are not usually considered in the existing urban runoff models..

The proposed model is associated with high modeling resolutions in both time and space. Temporally, majority of pesticide washoff by overland flow may occur during the early stage of precipitation, suggesting a time step in hours or minutes. Spatially, simulations of mitigation scenarios such as spray width change prefer a spatial resolution at inch (or centimeter) scale. In addition, urban pesticides are usually only applied on a small portion of the simulated surface. This results in high concentration gradient on the edge of pollution plume, and requires high resolution grid system for accurate and effective numerical calculation. The high resolution system also allows the use of spatially distributed input parameters (e.g., slope, surface roughness, irrigation rate) for simulating a heterogeneous pathway for pesticide runoff over impervious surfaces.

4.3 Validation

The formulations of pesticide release from concrete surface and its computer implementation will be first verified by the results of pesticide washoff studies in the literature (Harbourt *et al.*, 2009; Jiang *et al.*, 2010a; Jiang *et al.*, 2010b; Jorgenson and Young, 2010) and from the ongoing and proposed projects (e.g., “Mitigation of pesticide runoff from hard surfaces”, proposed by UC Riverside, 09/2011-12/2013).

For model valuation of pesticide transport in overland flow, the flow-weighted averages of pesticide concentrations at the bottom of the simulated slope will be reported within certain time interval, and compared to the measured pesticide runoff in driveway experiments. Two ongoing projects, i.e., Contract 10-C0085 (“Transfer processes and mitigation measures for pesticide runoff from homes”, 01/2011-12/2013) and Contract 10-C0121 (“Pesticide formulation: effects on washoff from concrete and modeling of transport”, 05/2011-12/2013), will be used for providing field measurements for the validation purpose. Additional data from other studies may also be used if available.

5. Timeline

12/2011	2/2012	4	6	8	10	12	2/2013	4	6	8
[1]										
[2.1]					[2.2]			[2.3]*		
	[3]									
					[4]					
								[5]*		

[1] Protocol reviews and discussions,
[2] Literature review and data collection for
[2.1] existing modeling studies for overland flow and chemical (may not be pesticides) transport over concrete surfaces;
[2.2] laboratorial washoff studies, and

[2.3] field runoff studies,
[3] Overland flow modeling,
[4] Pesticide fate and transport modeling, and
[5] Model verification and validation.

* The model development is proposed to be finished by August 2013, but the model validation may be extended to the end of 2013 and subject to the completion and result reporting of the contracted projects.

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