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Research Paper

Minimizing mosquito larval habitat within roadside stormwater treatment best management practices in southern California through incremental improvements to structure

Marco E. Metzger[a,*], Justin E. Harbison[a,1], Joseph E. Burns[a], Vicki L. Kramer[a], John H. Newton[b], John Drews[b], Renjie Hu[a]

[a] Vector-Borne Disease Section, Division of Communicable Disease Control, Center for Infectious Diseases, California Department of Public Health, 1616 Capitol Ave, MS-7307, Sacramento, CA 95814, USA

[b] Orange County Mosquito & Vector Control District, 13001 Garden Grove Blvd., Garden Grove, CA 92843

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ABSTRACT

A five-year study was conducted in Orange County, California to document the presence of standing water and the presence or absence of larval mosquitoes within 23 stormwater treatment Best Management Practices (BMPs) installed along State Route 73 by the California Department of Transportation. Findings were used to guide incremental improvements to BMP design and function with the aim of reducing the occurrence of standing water that persisted more than 96 h after precipitation. During the first year of monitoring, a number of structural and non-structural factors were identified as causes for standing water within BMPs suitable for mosquitoes. Uneven grades, inlet design and construction, and novel structural features were most frequently responsible for standing water, often exacerbated by sediment and debris accumulations and periodic or perennial non-stormwater flows. Subsequent modifications to BMPs eliminated or reduced the size of persistent standing water pools. The study demonstrated that mosquito larval habitat can be mitigated in BMPs designed to remain dry between precipitation events by collecting field data that identifies where post-construction structural and managerial changes are needed to eliminate or reduce unintended sources of standing water.

1. Introduction

The potential negative impacts of stormwater and urban runoff to public and environmental health have resulted in increasingly stringent stormwater management programs specifically directed at reducing the pollutant loads carried by runoff and the volume of water discharged downstream (Copeland, 2016, 2012). A principal component of such programs has been the implementation of actions, practices, and structures to mitigate the harmful effects of runoff collectively referred to as stormwater Best Management Practices (BMPs) (Ice, 2004; Minton, 2005; WEF and ASCE, 1998). Among these, structural treatment BMPs such as retention and detention basins are frequently employed in urban, suburban, and roadside environments to capture target pollutants from urban runoff and in some cases also to control the volume of water released into downstream waterways. An unintended consequence associated with the implementation of these structures is the potential for mosquito production when standing water captured by the BMP is accessible to these insects and is held long enough to allow for larval development (Metzger, 2004). There is a need for developing stormwater treatment BMPs that accomplish water quality and management objectives with minimal required maintenance, but which also minimize public health concerns associated with mosquitoes.

Numerous studies have documented mosquito production from both above- and belowground stormwater treatment BMPs, including species capable of transmitting disease pathogens such as West Nile virus (Gingrich et al., 2006; Harbison et al., 2010; Kwan et al., 2008; Metzger et al., 2008, 2003; Santana et al., 1994; Wallace, 2007). The proliferation of these structures in urban and suburban developments and along transportation corridors has resulted in an increase in the number of potential sources of mosquitoes in close proximity to humans (Harbison et al., 2010; Kwan et al., 2008; Metzger et al., 2011, 2008) and created additional burdens on public health agencies (Kluh et al., 2002). Determining whether or not a particular structure may produce mosquitoes is complex and dependent on a wide variety of factors that can contribute, singly or in combination, to the presence and availability of standing water suitable for mosquito development. Such

* Corresponding author at: California Department of Public Health, Vector-Borne Disease Section, 2151 Convention Center Way, Suite 218B, Ontario, CA 91764, USA.
E-mail address: marco.metzger@cdph.ca.gov (M.E. Metzger).

[1] Present address: Department of Public Health Sciences, Loyola University Medical Center, 2160 S. First Ave, Maywood IL 60153, USA.

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factors may include structural design and functions, errors made during construction, sediment and debris accumulations, maintenance intervals, and other site-specific natural or human influences (Metzger, 2004). In those systems not designed to hold permanent standing water, many of these potential issues can be eliminated through pre-construction planning, post-construction structural repairs and modifications, mitigation of non-stormwater flows, and routine maintenance (Metzger et al., 2008).

In 2002, the California Department of Transportation (Caltrans) initiated a project in Orange County to remove and replace existing stormwater treatment BMPs installed along State Route (SR) 73 with a variety of alternative treatment structures, mainly detention basins. The purpose of this effort was to achieve equal or greater pollutant removal performance and runoff management with BMP designs that required less maintenance, and simultaneously exclude mosquitoes by completely dewatering in less than 96 h and remaining dry between precipitation events. Caltrans purpose-built 23 BMPs to assess the water quality performance of specific designs, configurations, and components (Caltrans, 2008) and contracted with the California Department of Public Health, Vector-Borne Disease Section (CDPH\VBDS) to lead a five-year (2004–09) study aimed at minimizing unintended mosquito production within these structures. The objectives of the interagency collaboration were to develop, implement, and evaluate solutions to eliminate the occurrence of standing water suitable for mosquito larval development without significantly altering the water quality and runoff management targets of the structures. The presence of standing water, the identified or presumed causes for observed standing water, and the presence or absence of larval mosquitoes were documented. Findings were provided to Caltrans on a regular basis to guide incremental improvements to BMP design and function. The contribution of factors influencing potential mosquito production within BMPs is discussed, particularly with regard to the different structural features employed by Caltrans.

2. Materials and methods

2.1. Description and background of the project area and BMP study sites

State Route 73 is a 28 km highway in Orange County, California that extends from Interstate 405 in Costa Mesa to Interstate 5 in San Juan Capistrano intended to reduce congestion on existing north-south thoroughfares (Fig. 1). Completed in late 1996, most of SR-73 (19 km) is a limited-access toll highway named the San Joaquin Hills Transportation Corridor that traverses the San Joaquin Hills through many environmentally sensitive and pristine areas of the county. The topography varies from level to somewhat mountainous, with native vegetation consisting primarily of coastal sage scrub. During construction of the highway, 39 roadside stormwater treatment BMPs were installed within the right-of-way to mitigate highway-generated pollutants carried by runoff (Conrad, 1995). Following construction, ownership of the BMPs was transferred to Caltrans; however, concerns with the performance and maintenance costs associated with proprietary filtration material led Caltrans to remove all existing BMPs several years after their installation and replace them with different treatment technology BMPs (Caltrans, 2008).

Caltrans selected 23 sites (Fig. 1) to study the performance and maintenance requirements of 20 earthen detention basins that incorporated different inlet and outlet structures and basin configurations, two concrete basins designed to function as Gross Solids Removal Devices (GSRDs), and one bioretention basin with a linear radial GSRD inlet (Caltrans, 2008), for a total of 11 different design categories (Figs. 2 and 3; Table 1). A subsurface plastic liner was included in the construction of all earthen basins to ensure that no water escaped by infiltration during the stormwater treatment efficacy evaluation. All BMPs were designed to dewater within 48–72 h of a storm event; a time period Caltrans considered adequate to achieve desired water quality and runoff management objectives that also fell within the 96 h drawdown recommendations made by local, state, and federal public health agencies to prevent mosquitoes from completing their life cycle (CDC, 2012; CDPH, 2012; Metzger, 2004).

2.2. Monitoring for standing water and mosquitoes

Study sites were monitored by CDPH\VBDS for presence of standing water and larval mosquitoes between June 2004 and May 2009. At the onset of the study in June 2004, 17 of the 23 study sites had been built and by December 2006 all were completed. Monthly site visits were conducted during the first year to become familiar with the characteristics of individual BMPs, note the presence or absence of standing water and larval mosquitoes (i.e., larvae and/or pupae), and elucidate the cause and origin of observed standing water. Site visits were increased to 2 week intervals beginning in July 2005 through the end of the study.

All site inspections were conducted at least 4 days following any measured precipitation to allow ample time for captured runoff in the BMP to dewater as designed. When standing water was noted, dip samples combined with visual examination were used to determine the presence or absence of larval mosquitoes followed by field identification of larvae to genus (Darsie and Ward 2005). Standing water sources positive for mosquitoes were reported to the Orange County Mosquito & Vector Control District (OCMVCD) for larvicide treatment. Areas of persistent standing water, regardless of presence of mosquitoes, were reported to Caltrans along with detailed descriptions of the potential cause and origin. Caltrans evaluated sites with reported standing water and developed plans for mitigation that were implemented as soon as practicable. The success of corrective measures relative to the presence and size of standing water pools was evaluated by CDPH\VBDS during subsequent site visits. Precipitation data were provided by a weather station of the NOAA National Weather Service Forecast Office located at John Wayne Airport (http://www.weather.gov/climate/index.php?wfo=sgx). All sampled BMPs were within 22 km of this station.

3. Results

Over the course of the 5-year study period, BMPs were inspected on 99 different days (4–251 days after measured precipitation) resulting in a total of 2001 recorded observations between June 2004 and May 2009 (Table 1). No data was collected during November 2004 or during March 2006 due to frequent rainfall within the monitoring intervals. The monthly percentage of BMPs with standing water observed greater than 96 h after precipitation, monthly percentage with observed larval mosquitoes, and total monthly precipitation is summarized graphically in Fig. 4. Eight structural factors associated with the design and construction of BMPs and two non-structural (i.e., environmental) factors were identified by CDPH\VBDS as causes for standing water beyond the target 96 h maximum detention period (Table 2), particularly during the first year of monitoring. Uneven grades, inlet design and construction, and novel outlet features (e.g., skimmers) were most frequently responsible for standing water, often exacerbated by sediment and debris accumulations and periodic or perennial non-stormwater flows. The majority of structural repairs and modifications to mitigate standing water were made by Caltrans during the first year and a half of the study (June 2004–December 2005), with the greatest effort made at the beginning of the 2005–2006 rainy season between September and November 2005. The reported causes for standing water and the subsequent corrective measures taken by Caltrans are summarized in Table 2.

Standing water was observed 437/2001 (22%) individual site inspections during the study (Table 1). The monthly percentage of BMPs failing to drain within 96 h of recorded precipitation varied during the study period, but increased notably during months with greater than 20 mm total rainfall (Fig. 4). Following the major mitigation efforts