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Long-term characterization of residential runoff and assessing potential surrogates of fecal indicator organisms

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ABSTRACT

Investigations into the microbiological impacts of urban runoff on receiving water bodies, especially during storm conditions, have yielded general paradigms that influence runoff abatement and control management strategies. To determine whether these trends are present in other runoff sources, the physical, chemical, and microbiological components of residential runoff from eight neighborhoods in Northern and Southern California were characterized over the course of five years. Sampling occurred regularly and during storm events, resulting in 833 data sets. Analysis of runoff data assisted in characterizing residential runoff, elucidating differences between dry and storm conditions, and identifying surrogates capable of assessing microbiological quality. Results indicate that although microbial loading increases during storm events similar to urban runoff, annual microbial loading in these study sites principally occurs during dry conditions (24% storm, 76% dry). Generated artificial neural network and multiple linear regression models assessed surrogate performance by accurately predicting *Escherichia coli* concentrations from validation data sets ($R^2 = 0.74$ and 0.77, respectively), but required input from other fecal indicator organism (FIO) variables to maintain performance ($R^2 = 0.27$ and 0.18, respectively, without FIO). This long-term analysis of residential runoff highlights characteristics distinct from urban runoff and establishes necessary variables for determining microbiological quality, thus better informing future management strategies.

1. Introduction

Stormwater, passing through urban areas as runoff, is a significant source of nonpoint pollution of surface water in the United States. Runoff is less readily absorbed in developed regions due to impervious surfaces like roads and sidewalks. These waters can collect pathogens, fertilizers, heavy metals, and other pollutants for direct deposition into receiving bodies of water (U.S. Environmental Protection Agency, 2002a). Although often significantly higher in volume and pollutant concentration during storm events, a variety of other activities, such as household water use and industrial activities, regularly contribute to urban runoff during dry weather.

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However, investigations into these individual runoff components, specifically their quality and response to meteorological conditions, are limited (Reeves et al., 2004). Nevertheless, empirical runoff control and abatement strategies, historically termed 'best management practices,' (BMPs) typically focus on runoff generated during storm events and assume these applied measures inherently account for baseflows due to smaller runoff volumes containing fewer pollutants (U.S. Environmental Protection Agency, 2005). However, preventative strategies aimed at protecting water quality require an understanding of the components of runoff, specifically, their origin, magnitude, and impact on receiving waters.

Runoff generated from residential water use is one such component of general urban runoff, accounting for nearly 25% of all household water consumption (Kenny et al., 2009). Residential practices that generate runoff include excessive landscape watering, washing vehicles, plumbing leaks, and maintaining sidewalks/driveways. Due to their higher relative percentage of permeable surfaces, residential neighborhoods typically generate less runoff than their urban counterparts (Walters et al., 2011). As such, runoff management strategies applied to urban areas may be inappropriate for residential neighborhoods (Selvakumar and Borst, 2006). Additionally, a lack of residential runoff data regarding microbiological quality and the effects of meteorological conditions compounds this uncertainty (Bertrand-Krajewski, 2007). This issue was addressed with a long-term characterization of 28 different water quality parameters from eight neighborhoods in Northern and Southern California (NorCal and SoCal, respectively).

The analyses in this paper are focused on microbiological data used to characterize residential runoff during dry and storm conditions. Additionally, potential surrogates of *Escherichia coli* (EC) were assessed, with the goal of reducing the number of variables needed to determine the microbiological quality of runoff. Performing such analyses better informs residential runoff management strategies aimed at preventing surface water pollution.

2. Materials and methods

2.1. Study area and sampling methods

Eight California residential neighborhoods with similar parcel size and design, home age, household income, and exclusive residential land use served as study sites. These neighborhoods, located in Orange County (SoCal) and Sacramento County (NorCal), varied in the number of parcels, ranging from 152 to 460 homes, and exclusively conveyed runoff from surfaces to storm drain networks that discharge into nearby creeks, rivers, ponds, or tributaries via gravity. This closed network allowed the assumption that discharges collected during dry weather exclusively originated from human activities, such as landscape irrigation.

Samples were collected directly from drain outlets on a weekly or biweekly basis for three years, then changed to monthly sampling for another two years; additionally, samples were collected from each storm event throughout the five-year project. Storm events were defined as any rainfall event that resulted in significant increases in flow rates, and all storm events exceeded 0.2 cm of precipitation (Hathaway et al., 2010). Collection of all samples occurred either by manually placing a one-Liter amber glass bottle into the center of storm drain runoff to obtain a grab sample (NorCal), or via autosamplers (SoCal – see below), which produced a composite sample representing the previous 24 h. During low flow conditions, grab samples were collected by placing glass bottles below the edge of the storm drain. Differences in sampling methods arose from logistical constraints required to transport NorCal samples to laboratories located in SoCal. Samples were analyzed for 22 different physical and chemical parameters, as well as six fecal indicator microorganisms (FIO) (Table 1 and Supplementary Table 1). Onsite analyses occurred when available; otherwise, samples were transported on ice to SoCal for analyses that occurred on the same day as collection.

2.2. Physical and chemical parameters

Physical measurements, such as water depth and velocity, were obtained every two minutes from a Sigma 950 Area Velocity Bubbler Flow Meter coupled with a velocity only wafer sensor (Hach Company, Loveland, CO Model 3248 and 88006-25, respectively). Velocity measurements obtained from the meter, coupled with water depth and pipe diameter, permitted calculations of flow rate through the continuity equation. Furthermore, integrated components on the flow meter permitted other physical measurements including temperature, pH, electrical conductivity, and precipitation.

2.3. Microbiological methods

Runoff samples were analyzed for FIO; total coliforms (TC), EC, enterococci (ENT), *Clostridium perfringens* (CP), somatic coliphage (SC), and male-specific coliphage (MS). Six different indicator organisms were chosen for this study because no microbiological standard for runoff water quality exists.

2.3.1. Bacteria

Concentrations of fecal indicator bacteria were determined through membrane filtration according to protocols listed in Table 1 and Supplementary Table 1. Briefly, samples were diluted in phosphate buffered saline before passing 10 mL through S-Pak 0.45-μm membrane filters (EMD Millipore Corporation, Billerica, MA) under vacuum suction. The membrane filters were then placed on appropriate differential culture media and incubated under appropriate conditions overnight before enumerating colony-forming units (CFU).

2.3.2. Coliphage

Coliphage analysis followed the single agar layer procedure, method 1602 (U.S. Environmental Protection Agency, 2001). Specifically, EC F_{amp} (American Type Culture Collection, Manassas, VA – ATCC#700891) was used for male-specific coliphage (control MS2 – ATCC#15597-B1), while EC CN-13 (ATCC#700609) was used for somatic coliphage detection (control ΦX-174 – ATCC#13706-B1). One milliliter of the bacterial host, grown to log phase in tryptic soy broth containing appropriate antibiotics, was transferred to 10 mL of a double